NEW

HOW IT WORKS

WORLD OF TOMORROW

PLUS: AMAZING GADGETS INSIDE!

Digital Edition

FUTURE

THIRD EDITION

EVERYTHING YOU NEED TO KNOW ABOUT THE FUTURE

WELCOME TO

HOW IT WORKS WORLD OF TOMORROW

Do you ever wish you had a crystal ball so you could take a peek at what is to come in the distant future? Well, now you can, with this new edition of How It Works World of Tomorrow! While it's no magical artefact, it does offer a glimpse of future developments in transport, medicine, entertainment and space travel based on the innovations taking place in the present day, and speculations made by scientists and engineers. Learn more about how humans will live, interact and better the planet we live on (as well as other planets) in the future. You can expect flying cars, moon colonies and bionic limbs, but you'll also discover how virtual reality will develop to influence every part of society, if you will be able to 3D print a customisable pizza, how our smartphones will soon bend to fit in our pocket and how we might cure big killers like cancer . . . Whether you want to know if we'll leave our roads and pavements behind, or whether Elon Musk will succeed in his mission to bring human settlements to Mars, you will find the answer in this book. No crystal ball required.

HOW IT WORKS
WORLD OF TOMORROW

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bookazine series

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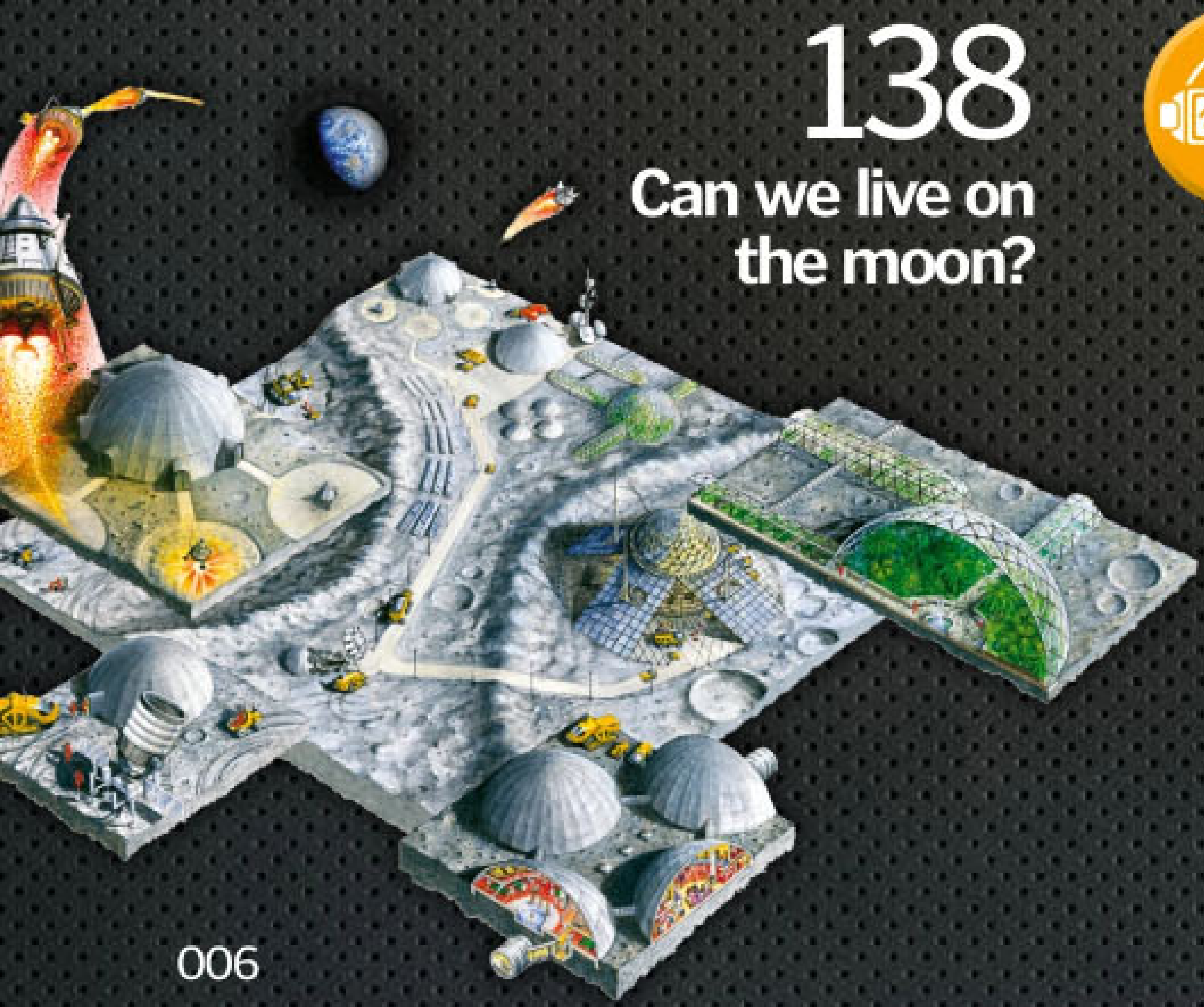

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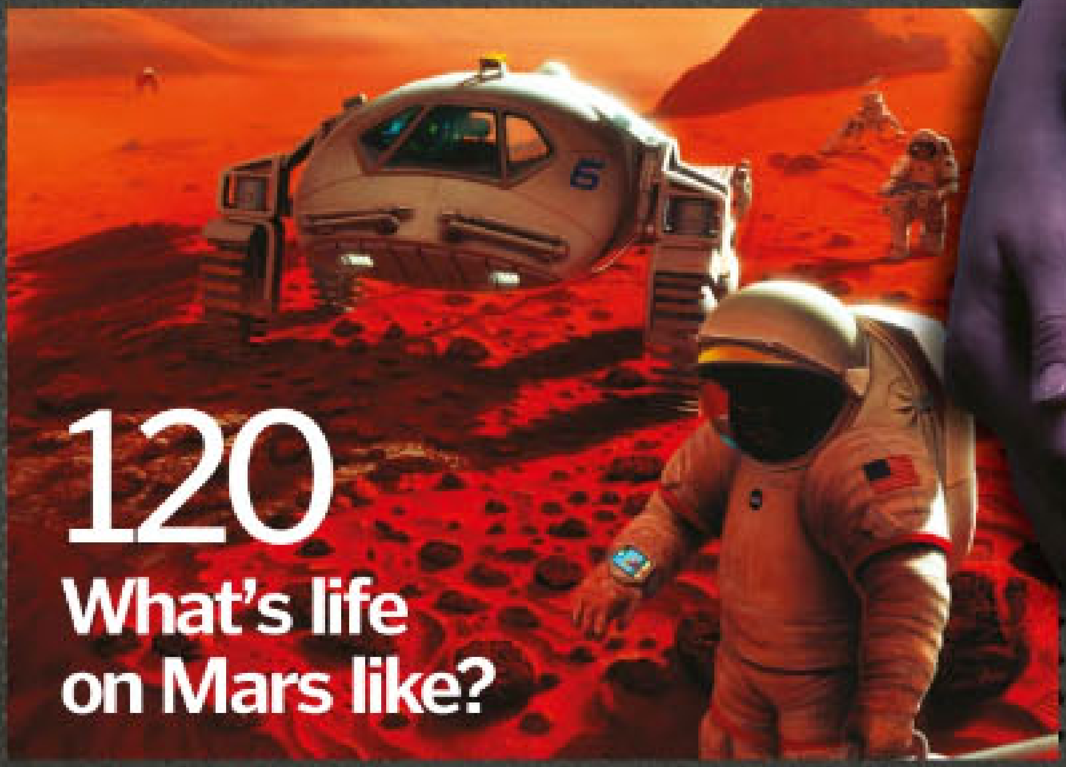

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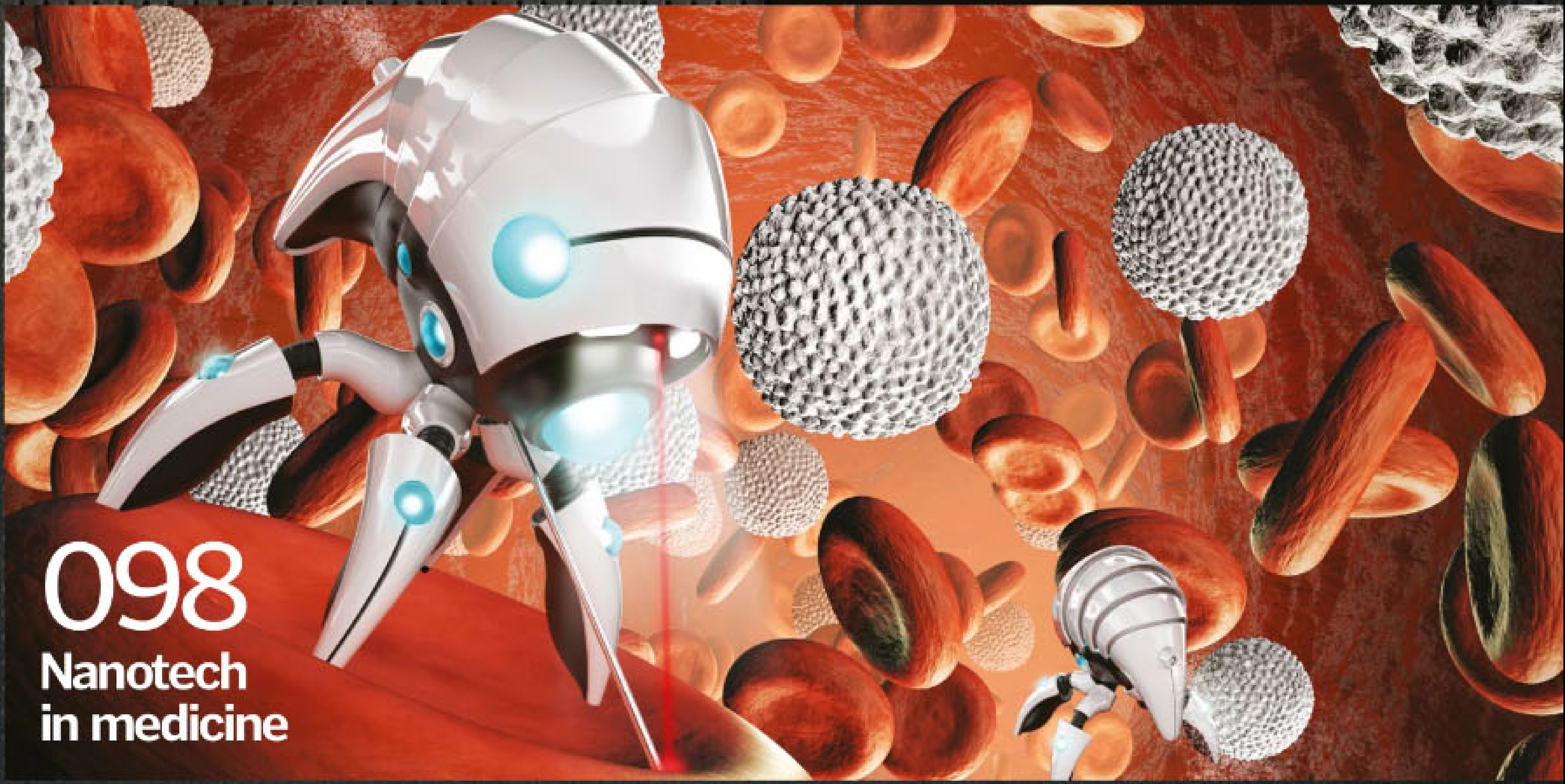

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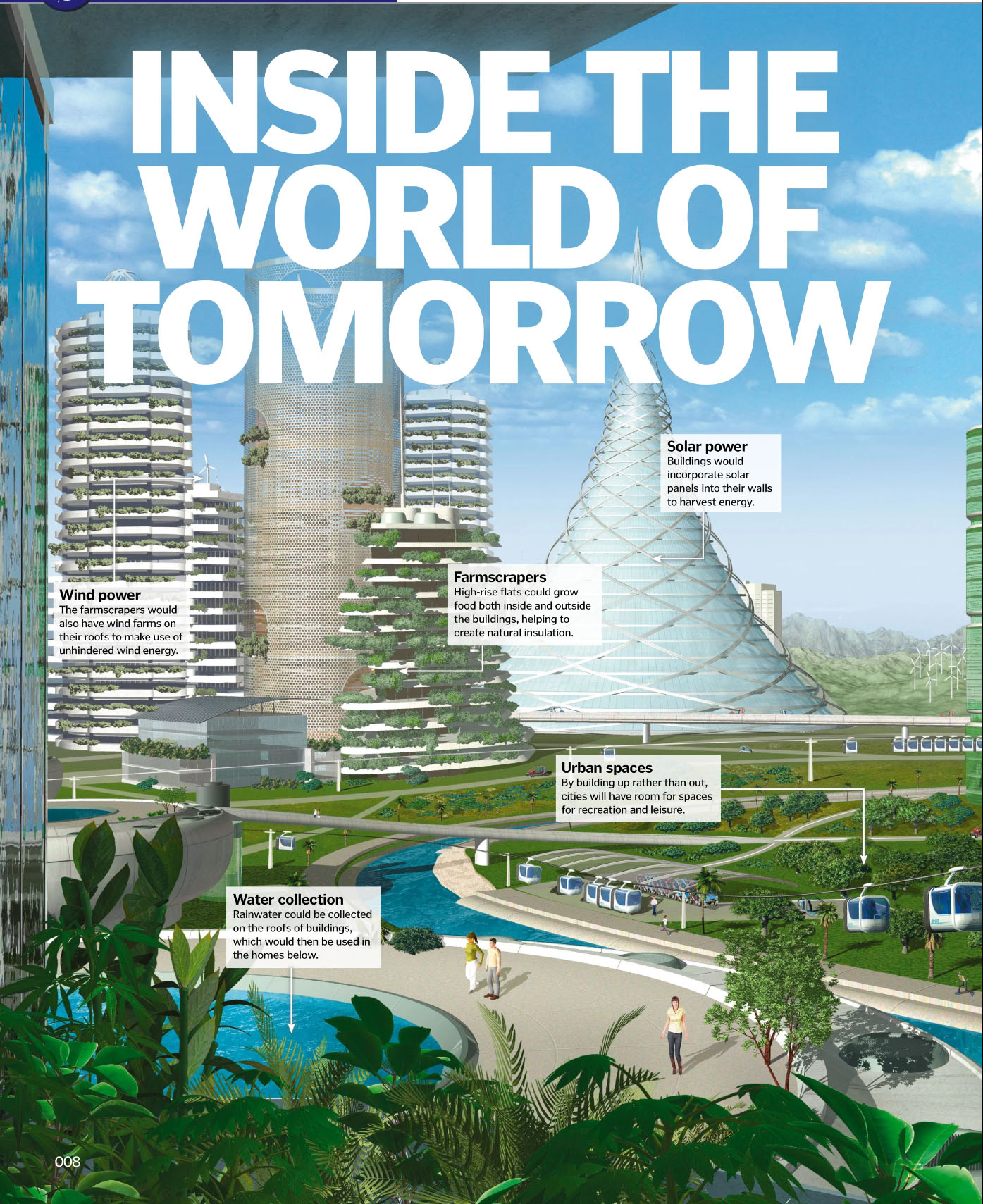
INSIDE THE WORLD OF TOMORROW



Solar power
Buildings would incorporate solar panels into their walls to harvest energy.

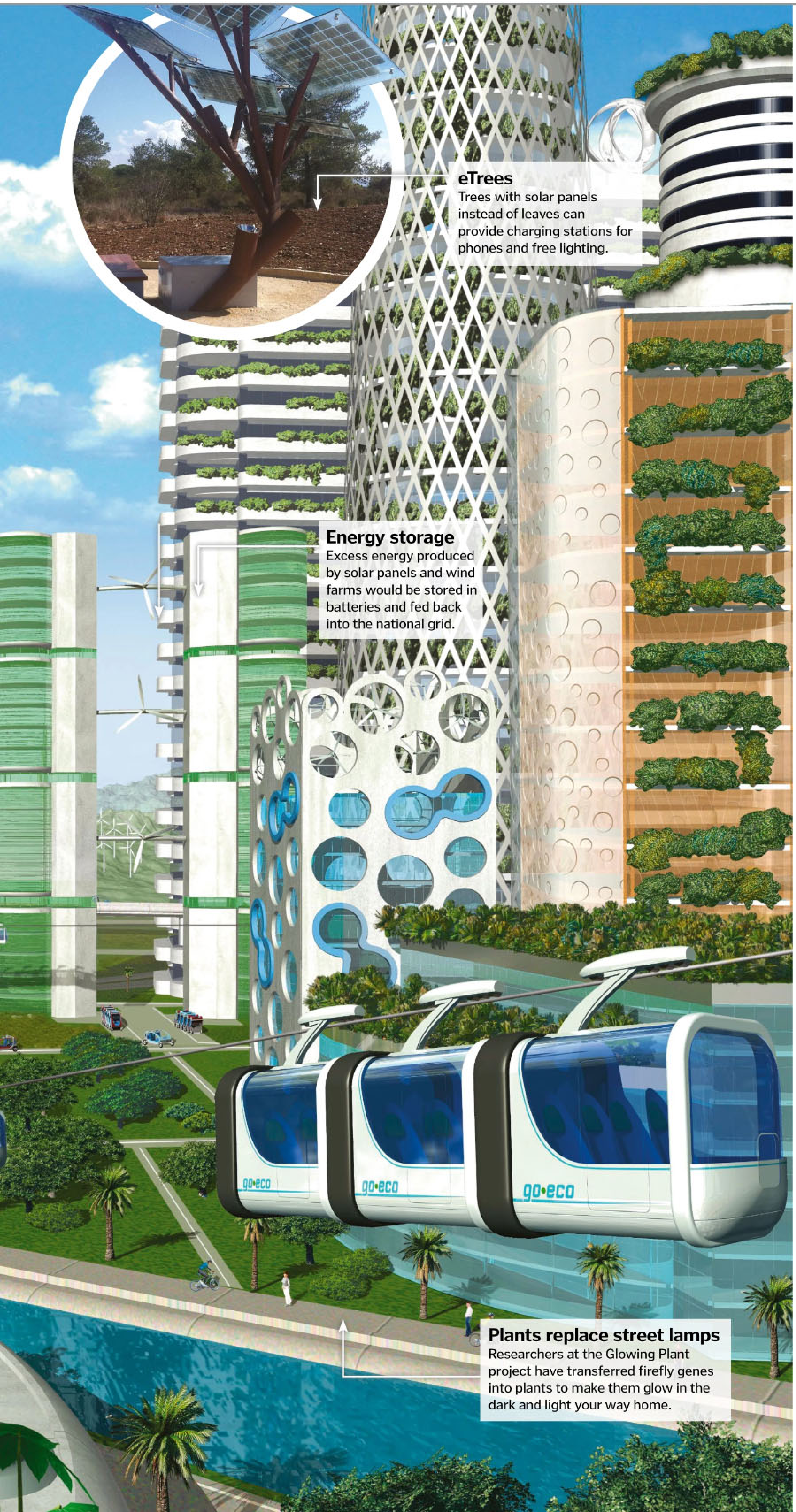
Wind power
The farmscrapers would also have wind farms on their roofs to make use of unhindered wind energy.

Farmscrapers
High-rise flats could grow food both inside and outside the buildings, helping to create natural insulation.

Urban spaces
By building up rather than out, cities will have room for spaces for recreation and leisure.

Water collection
Rainwater could be collected on the roofs of buildings, which would then be used in the homes below.

DID YOU KNOW? *Solar power is expected to become the largest source of electricity by 2050*



eTrees
Trees with solar panels instead of leaves can provide charging stations for phones and free lighting.

Energy storage
Excess energy produced by solar panels and wind farms would be stored in batteries and fed back into the national grid.

Plants replace street lamps
Researchers at the Glowing Plant project have transferred firefly genes into plants to make them glow in the dark and light your way home.

Experience the lean, green cities we'll soon be living in

Major cities are often viewed as grey, energy-guzzling monoliths, but the cities of the future could change everything. As the planet's store of fossil fuels dries up, we are looking for new ways to power our cities in sustainable but spectacular-looking ways.

Skyscrapers will become towering greenhouses as vertical farming takes hold. Crops would be grown between storeys, taking advantage of the Sun's energy while using minimal ground space. These ecological super-buildings would have photovoltaic solar-cell facades and be topped by wind turbines, making these homes the ultimate self-sustaining structures.

Tomorrow's city centres could look very different as groups gather below solar powered trees. These so-called eTrees offer more than just shade, as the energy produced from the solar panels transforms them into mobile phone charging stations, free Wi-Fi and night lighting. The solar energy also activates an LCD screen that displays information such as the weather and educational content.

Building upward would allow plenty of room on the ground for urban social areas as well as luminous plants. These are implanted with light-giving compounds known as luciferins, which will make the greenery glow at night as a cost-effective and eco-friendly method of illuminating tomorrow's cities.

Far from being a scary, soulless world as shown in movies like *Judge Dredd* and *Blade Runner*, the future cities promise to be bright, spacious and green, making the most of the amazing natural resources we have at our disposal already.

Virtual fitting rooms
This tech is already here! Some stores offer you the chance to superimpose clothes onto your body using a tablet or smartphone app.

© Science Photo Library; Getty; Corbis; Dreamstime

TOMORROW'S TRANSPORT

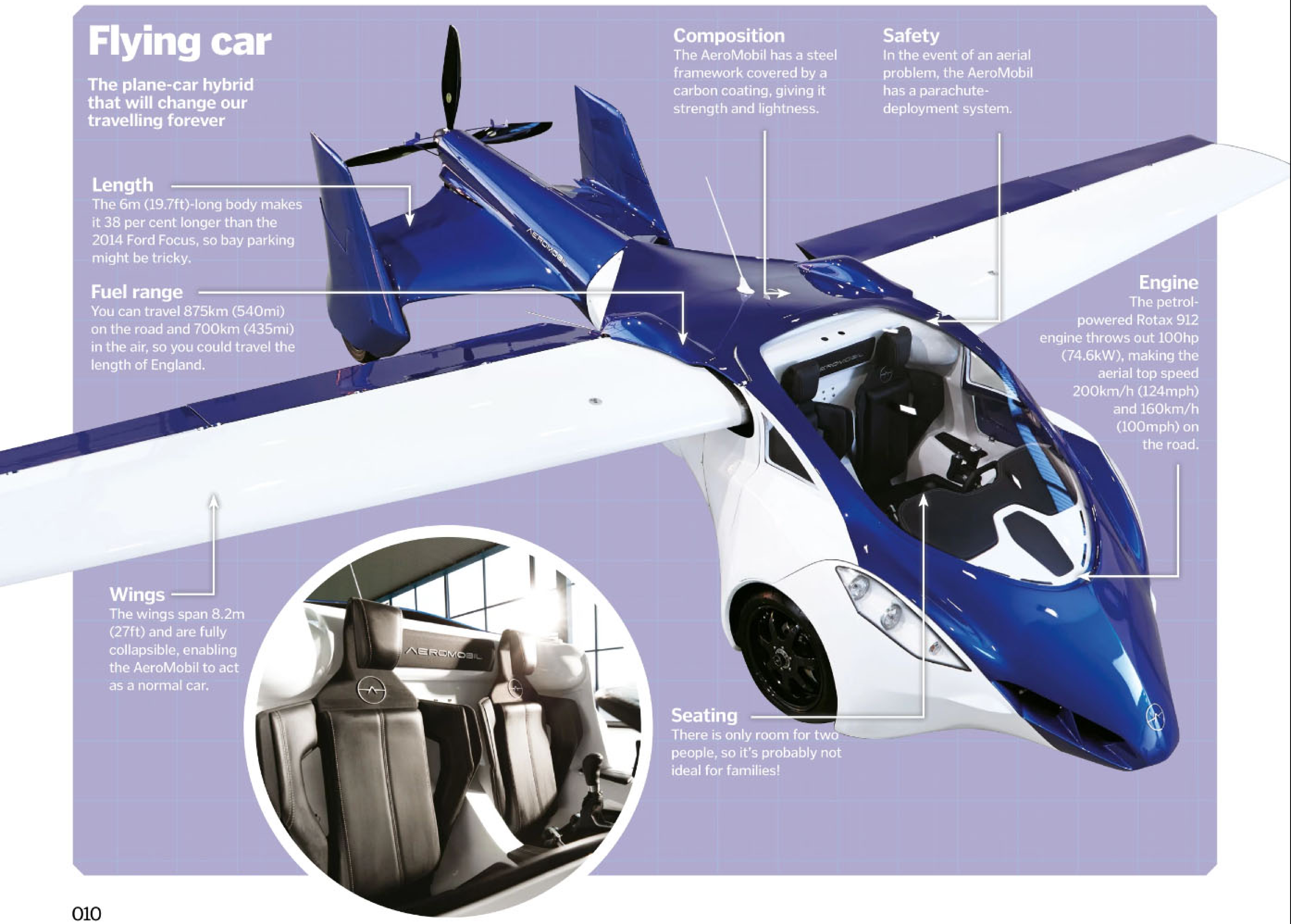
Why getting from A to B will soon become a breeze

When you hear the term 'transport of the future' your mind will generally turn to flying cars. Excitingly, they're already on their way. AeroMobil has unveiled the third version of its flying vehicle. Capable of switching in seconds between car and plane, you could wing your way to your destination, free from traffic jams and roadworks. On the ground, the AeroMobil uses regular petrol and fits into any standard parking space, but can reach 200 kilometres (124 miles) per hour in the air thanks to its Rotax 912 engine. This would reduce the traffic in future cities, making the streets safer for people on the ground.

Also, companies such as Amazon and DHL are trialling drones that can deliver parcels under 2.3 kilograms (five pounds), which Amazon says makes up 86 per cent of their deliveries. The use of drones will clear the streets and air as they will be battery or solar powered.

If you still felt like you wanted to stay on the ground, however, driverless taxis could ferry you around. The Google driverless car has already completed over 1,125,000 kilometres (700,000 miles) of accident-free driving using GPS satellites to map routes and on-board cameras to search for hazards.

These cars could be used as taxis – which would be summoned by a smartphone app – and would drive closer to each other and more efficiently than human drivers, meaning that no one need ever own a car. Unless it's an amazing flying car, that is.



Flying car

The plane-car hybrid that will change our travelling forever

Length
The 6m (19.7ft)-long body makes it 38 per cent longer than the 2014 Ford Focus, so bay parking might be tricky.

Fuel range
You can travel 875km (540mi) on the road and 700km (435mi) in the air, so you could travel the length of England.

Wings
The wings span 8.2m (27ft) and are fully collapsible, enabling the AeroMobil to act as a normal car.

Composition
The AeroMobil has a steel framework covered by a carbon coating, giving it strength and lightness.

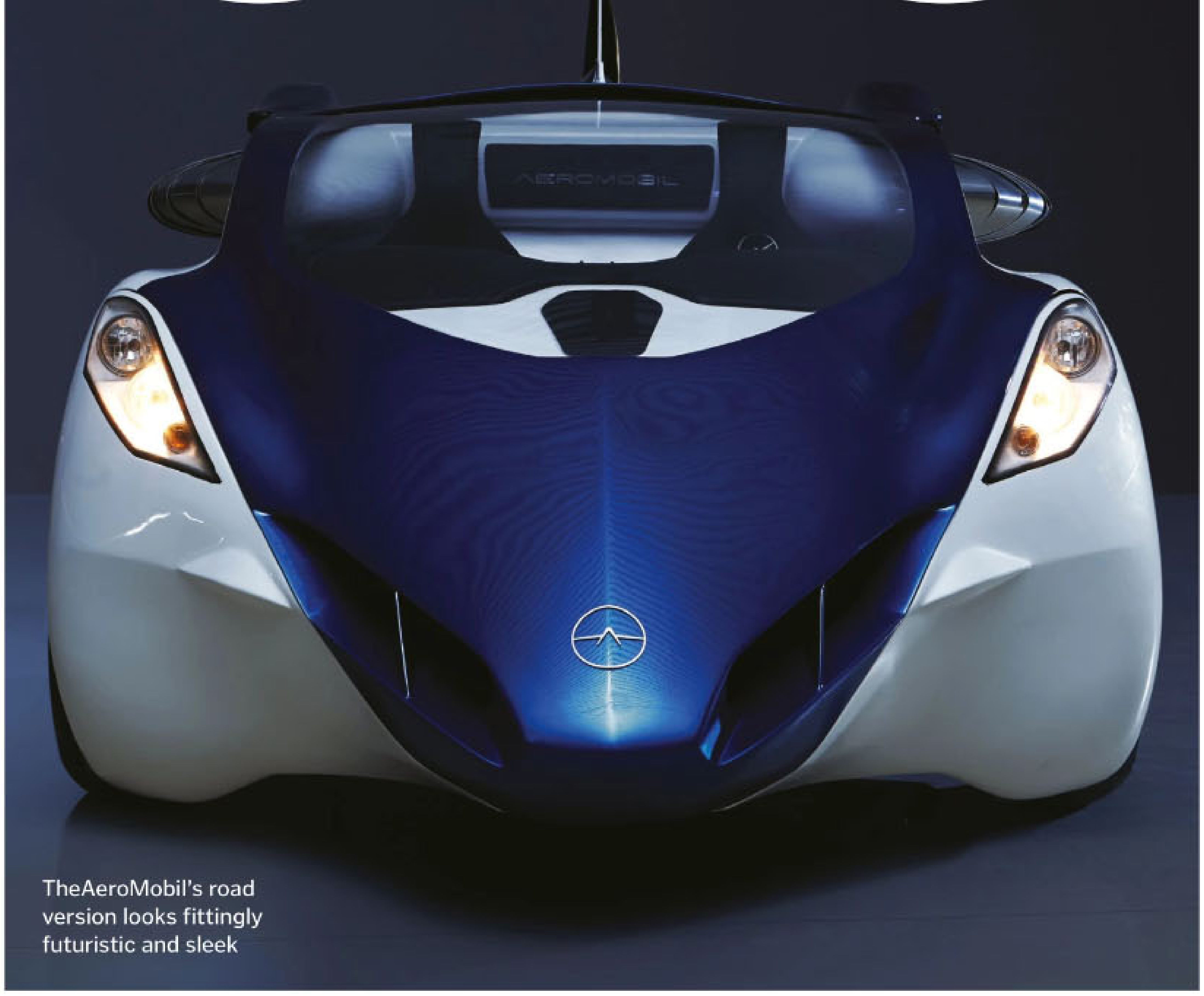
Safety
In the event of an aerial problem, the AeroMobil has a parachute-deployment system.

Engine
The petrol-powered Rotax 912 engine throws out 100hp (74.6kW), making the aerial top speed 200km/h (124mph) and 160km/h (100mph) on the road.

Seating
There is only room for two people, so it's probably not ideal for families!

DID YOU KNOW? *Even though it's a flying car, the AeroMobil uses regular gasoline*

The AeroMobil's dashboard is a little more complicated than today's cars'



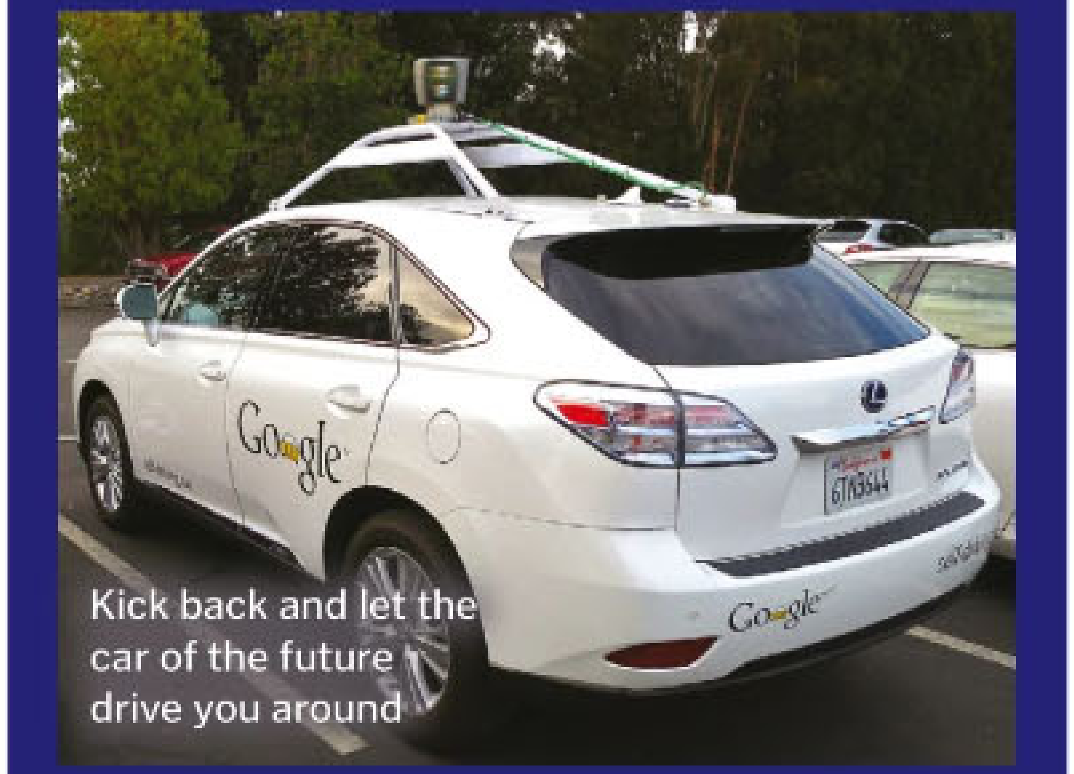
TheAeroMobil's road version looks fittingly futuristic and sleek

Delivery drones

At the moment delivery companies spend huge sums of money and use enormous amounts of fuel on delivering parcels, but in the city of the future drones could take on the task. Amazon and DHL are testing out drones that could deliver the majority of their products. These autonomous flying vehicles are lightweight and can be pre-programmed to reach their destination, guided by satellites.

They could deliver to hard-to-reach areas such as islands and take a huge number of vehicles off the roads. As they are powered either by batteries or solar power, they wouldn't be a drain on resources like delivery trucks either.

At the moment it is still illegal in the US for Amazon to use their drones for commercial reasons, although the company is in talks with the FAA to work around this. As the technology is already there it is looking increasingly likely that these devices could be in our skies within the next few years.



Kick back and let the car of the future drive you around

Driverless taxis

There is a very good chance that in the future, no one need ever own a car. Just like London and New York's bike-rental scheme, driverless cars could be summoned to your house and drive you to work. As they will drive themselves with much quicker reactions than humans and can't be distracted, they will be able to run at a steady speed, closer together and with fewer accidents, removing the main causes of traffic jams. Rooftop cameras will use lasers to scan the road ahead at a range beyond that of human vision. A second camera will look to the sides for hazards like pedestrians or animals. The guidance system will use GPS, altimeters and gyroscopes to keep track of where it is and where it is going. As 90 per cent of a car's life is spent parked, autonomous hire cars could become the most efficient way to get around.

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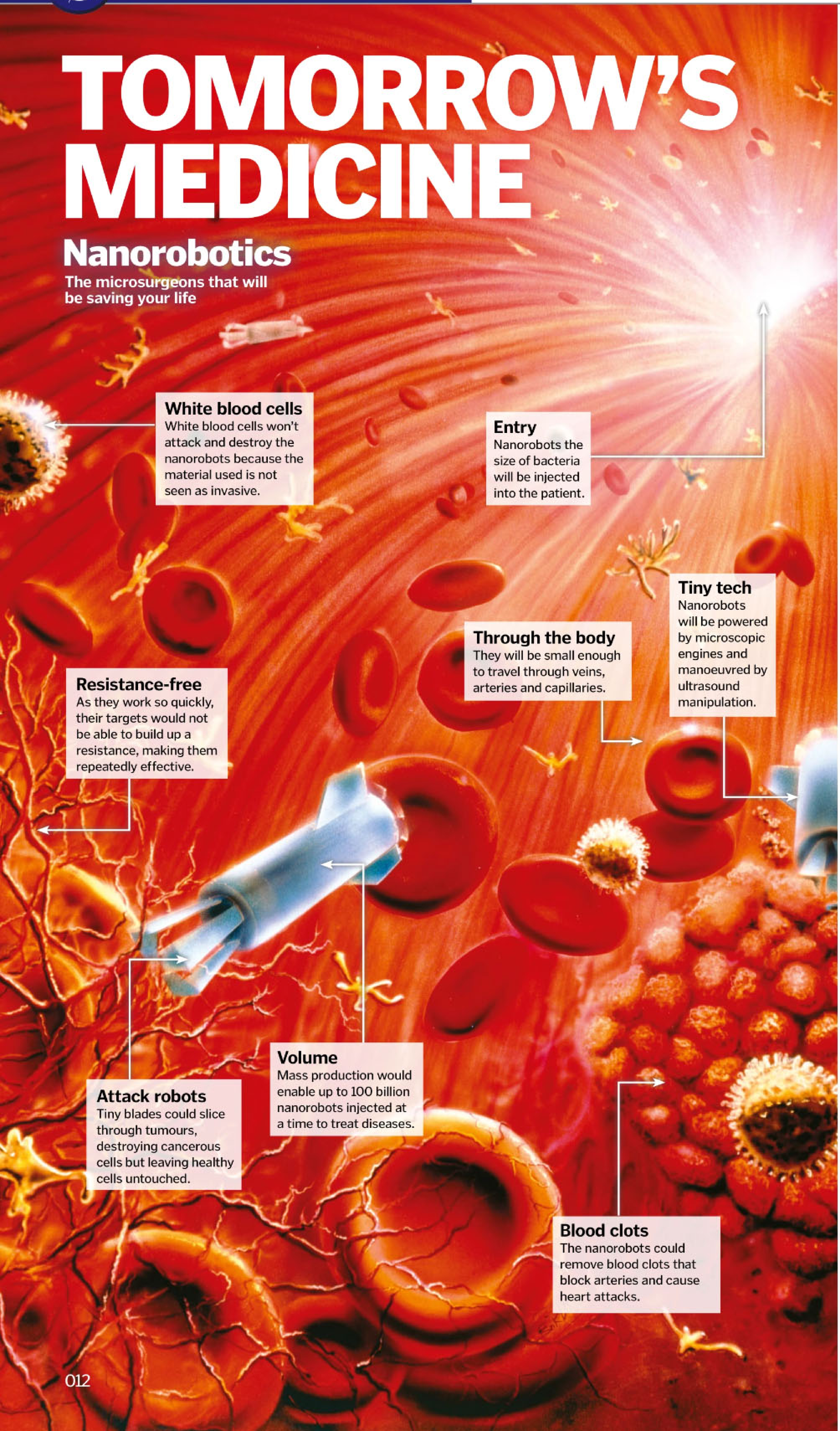
TOMORROW'S MEDICINE

Nanorobotics

The microsurgeons that will be saving your life



White blood cells
White blood cells won't attack and destroy the nanorobots because the material used is not seen as invasive.

Entry
Nanorobots the size of bacteria will be injected into the patient.

Tiny tech
Nanorobots will be powered by microscopic engines and manoeuvred by ultrasound manipulation.

Through the body
They will be small enough to travel through veins, arteries and capillaries.

Resistance-free
As they work so quickly, their targets would not be able to build up a resistance, making them repeatedly effective.

Volume
Mass production would enable up to 100 billion nanorobots injected at a time to treat diseases.

Attack robots
Tiny blades could slice through tumours, destroying cancerous cells but leaving healthy cells untouched.

Blood clots
The nanorobots could remove blood clots that block arteries and cause heart attacks.

The microscopic tech that saves your life from within

The area of nanomedicine is one that is advancing so rapidly that doctors could soon be piloting miniature robots through your body to diagnose and even battle illness. It is expected that within 20 years, molecular manufacturing will have reduced the size of robots to roughly the size of bacteria, meaning they can enter the body to spot and even cure disease.

The miniscule robots could be programmed to behave like a white blood cell, seeking out illness-causing bacteria or germs, latching onto them and slicing them up into molecules too small to do any further damage. Doctors could then remove the robots by using an ultrasound signal to direct the robots toward the kidneys where they would get washed out in urine.

Another potential use for nanorobots in medicine is actual surgery. A set of chromosomes would be manufactured outside the body and attached to a nanorobot. This would head straight toward a diseased cell, remove the damaged chromosomes and replace them with the healthy ones.

Another fascinating area of study is anti-ageing. Researchers have managed to restore the health of cells in a two-year-old mouse making it as fit as a six-month-old mouse. By injecting nicotinamide adenine dinucleotide (NAD) into the mice, scientists increased the level of communication between cells. This is very important, as a lack of communication between cells is heavily linked to diabetes, dementia and cancer. It's hoped that this scientific breakthrough will ultimately be proven successful in humans.

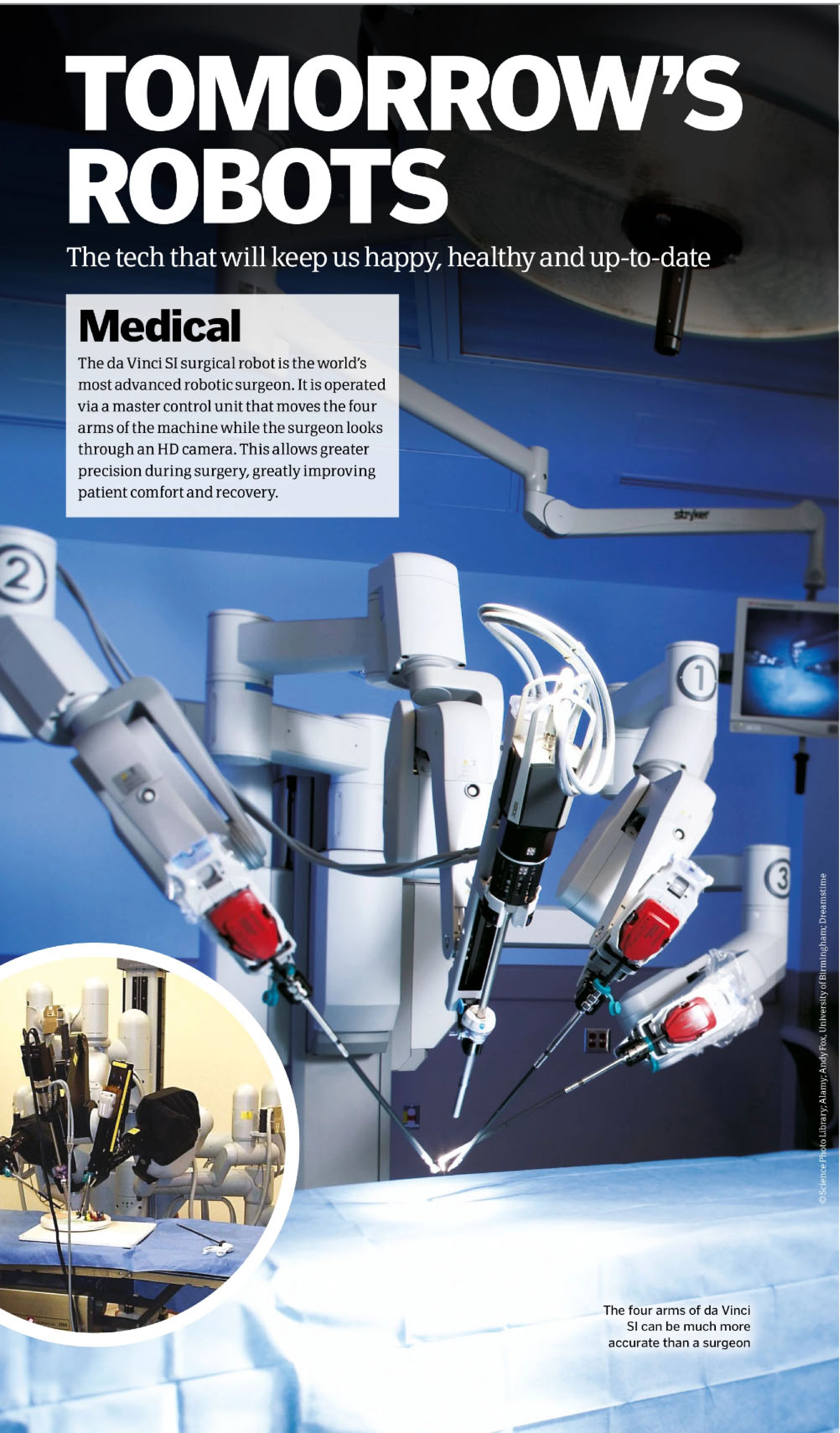
DID YOU KNOW? *The Boris 2 requires countless calculations to assess the size, weight and shape of unfamiliar objects*

TOMORROW'S ROBOTS

The tech that will keep us happy, healthy and up-to-date

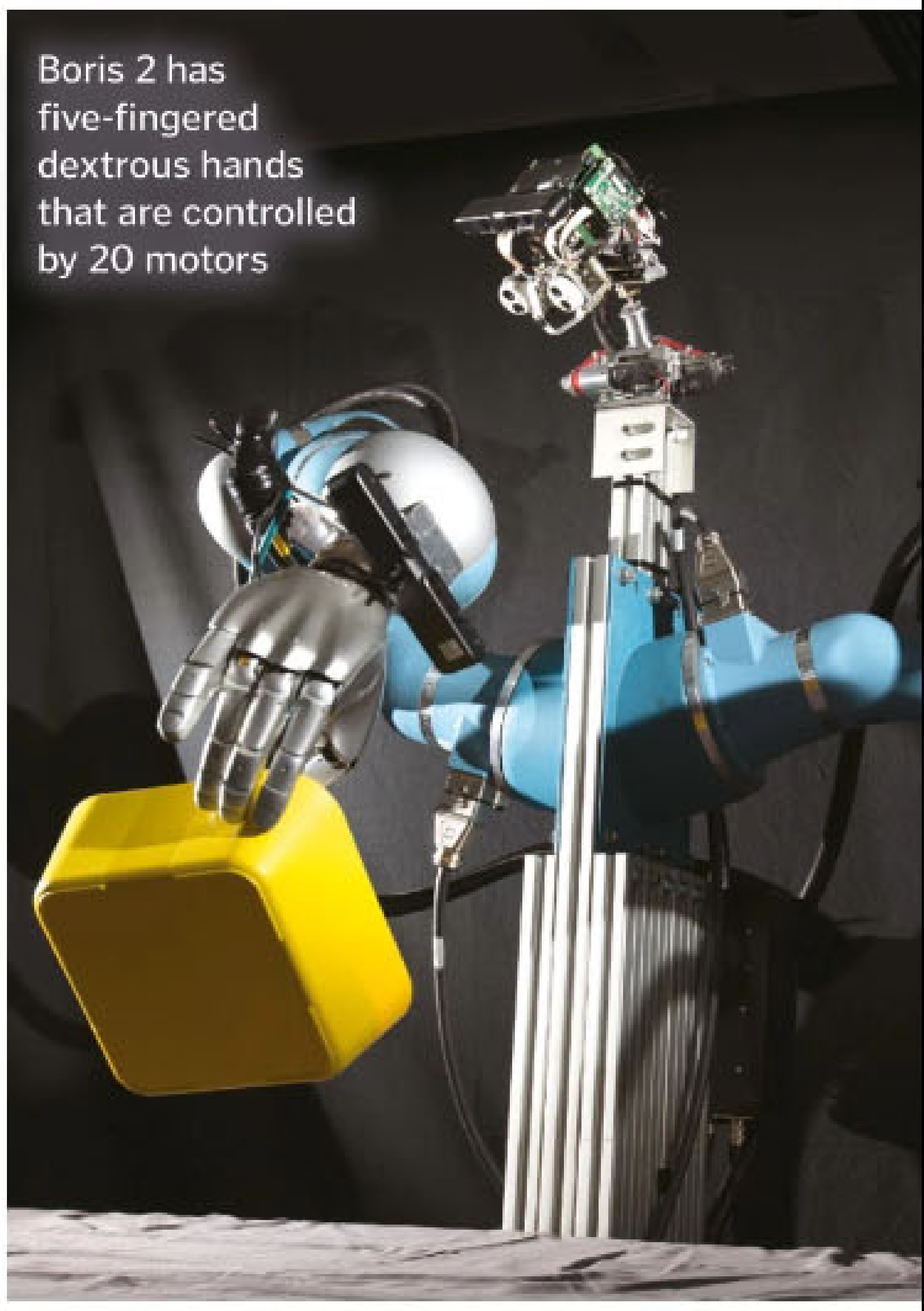
Medical

The da Vinci SI surgical robot is the world's most advanced robotic surgeon. It is operated via a master control unit that moves the four arms of the machine while the surgeon looks through an HD camera. This allows greater precision during surgery, greatly improving patient comfort and recovery.



The four arms of da Vinci SI can be much more accurate than a surgeon

© Science Photo Library; Alamy; Andy Fox, University of Birmingham; Dreamstime



Boris 2 has five-fingered dextrous hands that are controlled by 20 motors

Domestic

A robot called Boris 2 is one of the first in the world to intelligently grip unfamiliar objects. Developed by scientists at the University of Birmingham, the autonomous robot was designed with loading the dishwasher in mind – a chore that encompasses a range of general manipulation tasks.

Pepper understands your emotions and can also express its own

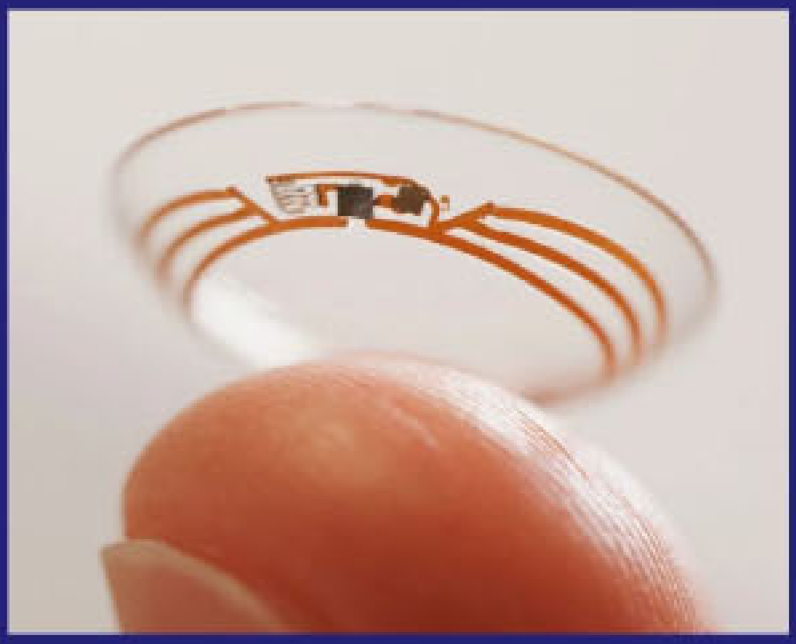
Recreation

Pepper is a humanoid robot designed to live with us. Sensors are used to gauge your facial expressions, listen to you, learn your body language and react accordingly. It's a social robot that will try to cheer you up when you're sad by playing your favourite song, for example.

AUGMENTED WORLD

Discover what we'll see through the augmented-reality contact lenses

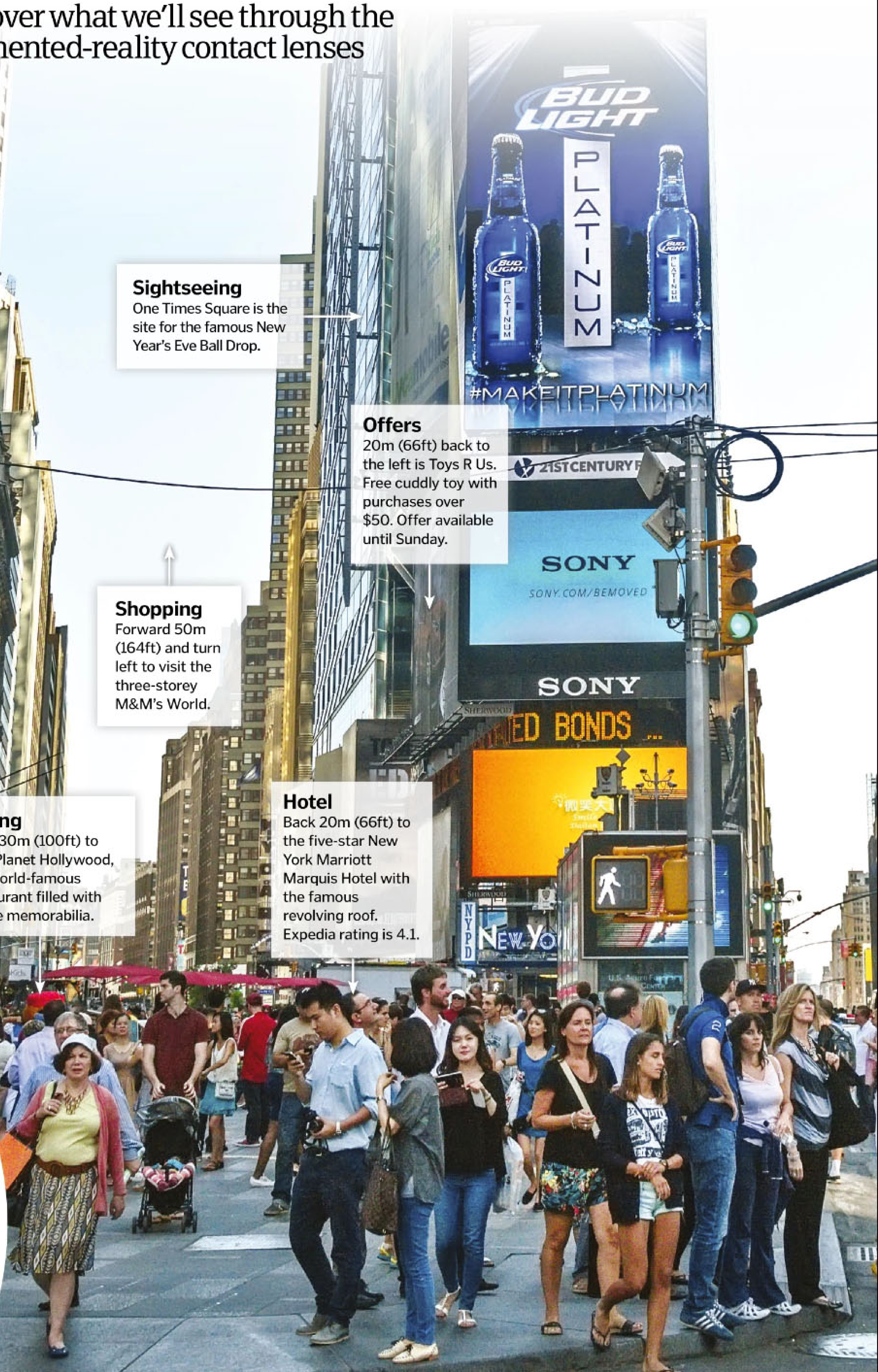
Could smart lenses replace your smartphone?



Smart lenses are contact lenses that display information such as routes, weather and your Facebook news feed into your peripheral vision. At the moment, the most likely team to crack this is Innovega with its iOptik contact lens, but this system still uses a pair of glasses that project semi-transparent screens onto the lens. The lens contains optical micro-components that change the angle of the light, focusing it into the pupil. This helps the wearer to focus on the near-eye object they otherwise wouldn't have been able to.

It is hoped that within three years a working prototype will be available that does away with the glasses entirely, using a microcamera embedded into the lens itself.

It is already possible for technology to be implanted into a contact lens. A team from South Korea has mounted an LED onto a normal contact lens, which shows the potential of adding technology to these optical aids.



Sightseeing
One Times Square is the site for the famous New Year's Eve Ball Drop.

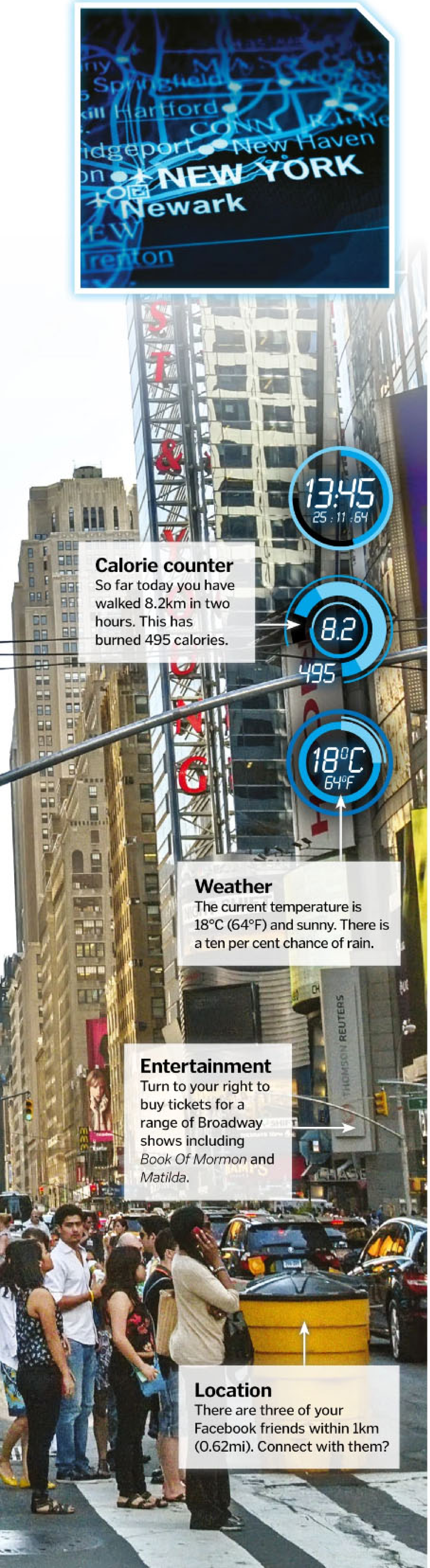
Offers
20m (66ft) back to the left is Toys R Us. Free cuddly toy with purchases over $50. Offer available until Sunday.

Shopping
Forward 50m (164ft) and turn left to visit the three-storey M&M's World.

Dining
Back 30m (100ft) to visit Planet Hollywood, the world-famous restaurant filled with movie memorabilia.

Hotel
Back 20m (66ft) to the five-star New York Marriott Marquis Hotel with the famous revolving roof. Expedia rating is 4.1.

DID YOU KNOW? *Although it's a futuristic method, the Z Machine has actually been in use since 1996*



Calorie counter
So far today you have walked 8.2km in two hours. This has burned 495 calories.

Weather
The current temperature is 18°C (64°F) and sunny. There is a ten per cent chance of rain.

Entertainment
Turn to your right to buy tickets for a range of Broadway shows including *Book Of Mormon* and *Matilda*.

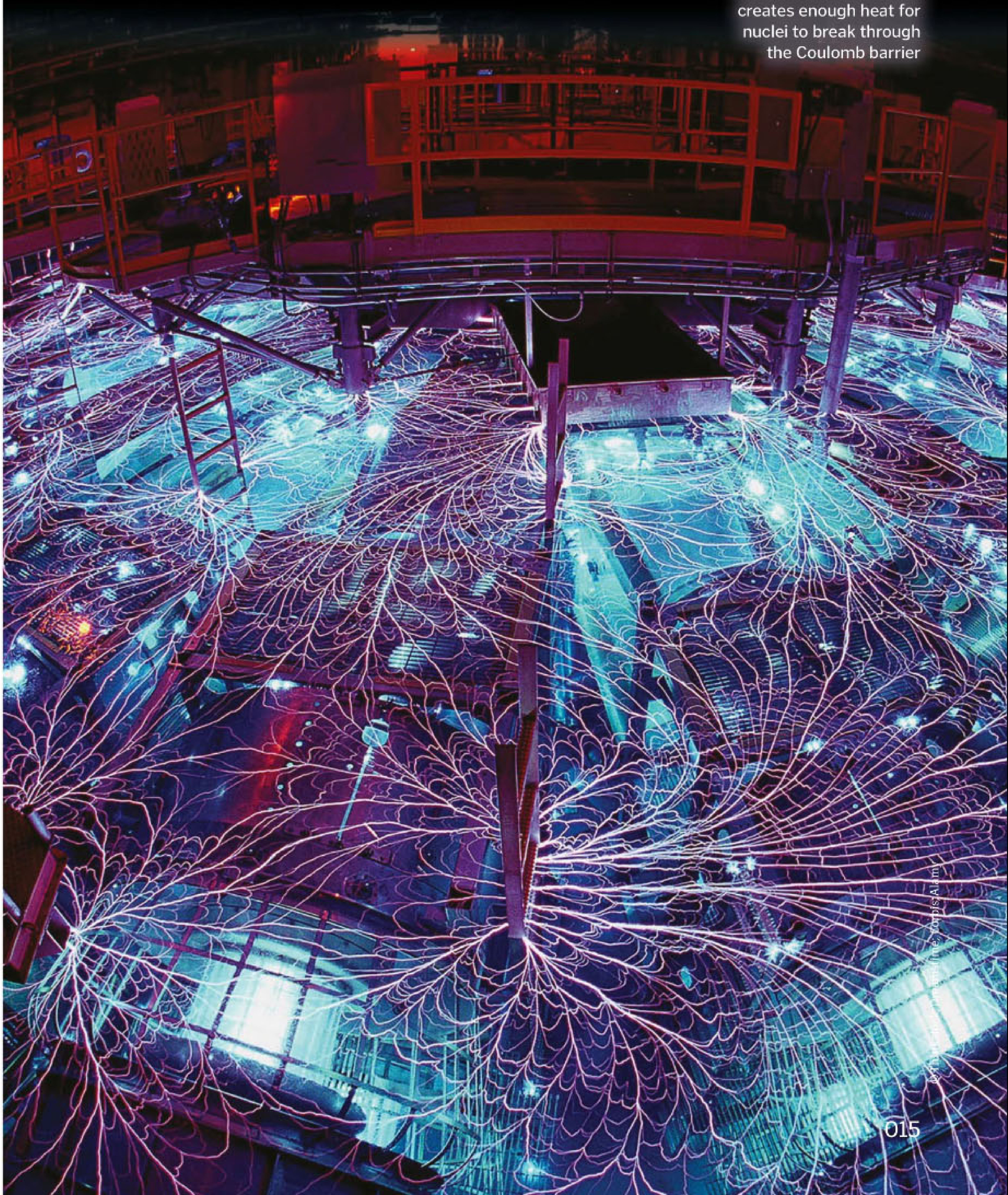
Location
There are three of your Facebook friends within 1km (0.62mi). Connect with them?

TOMORROW'S ENERGY

Fusion power: clean energy for tomorrow's power stations

Nuclear fusion is an incredibly exciting new direction that could provide Earth with huge amounts of clean energy. In nuclear fusion, helium nuclei are forced together to create a new atomic nucleus. The atomic mass of the two nuclei is greater than the mass of the resulting nucleus, so the extra mass is given off as energy. This can be harvested for practical uses.

The main barrier to nuclear fusion is temperature. Nucleons are held together by strong forces, while an electromagnetic force tries to pry them apart. When protons come into close contact, the electromagnetic force pushes them apart in what is called the Coulomb barrier. 40 million degrees Celsius (72 million degrees Fahrenheit) of heat is needed to break through the Coulomb barrier and allow the nuclei to fuse. This extreme heat could be provided by the Z Machine produced by Sandia National Laboratories, USA. This machine uses electricity to create radiation that heats the walls of the facility to nearly 2 billion degrees Celsius (3.6 billion degrees Fahrenheit).


The amazing Z Machine creates enough heat for nuclei to break through the Coulomb barrier

[illegible] Corbis; Alamy

COLONISING MARS

The tech that will help us go where no man has gone before

Ever since Neil Armstrong set foot on the Moon, there have been dreams to colonise other bodies in the Solar System, something that is becoming increasingly viable thanks to advancements in space travel and space suits.

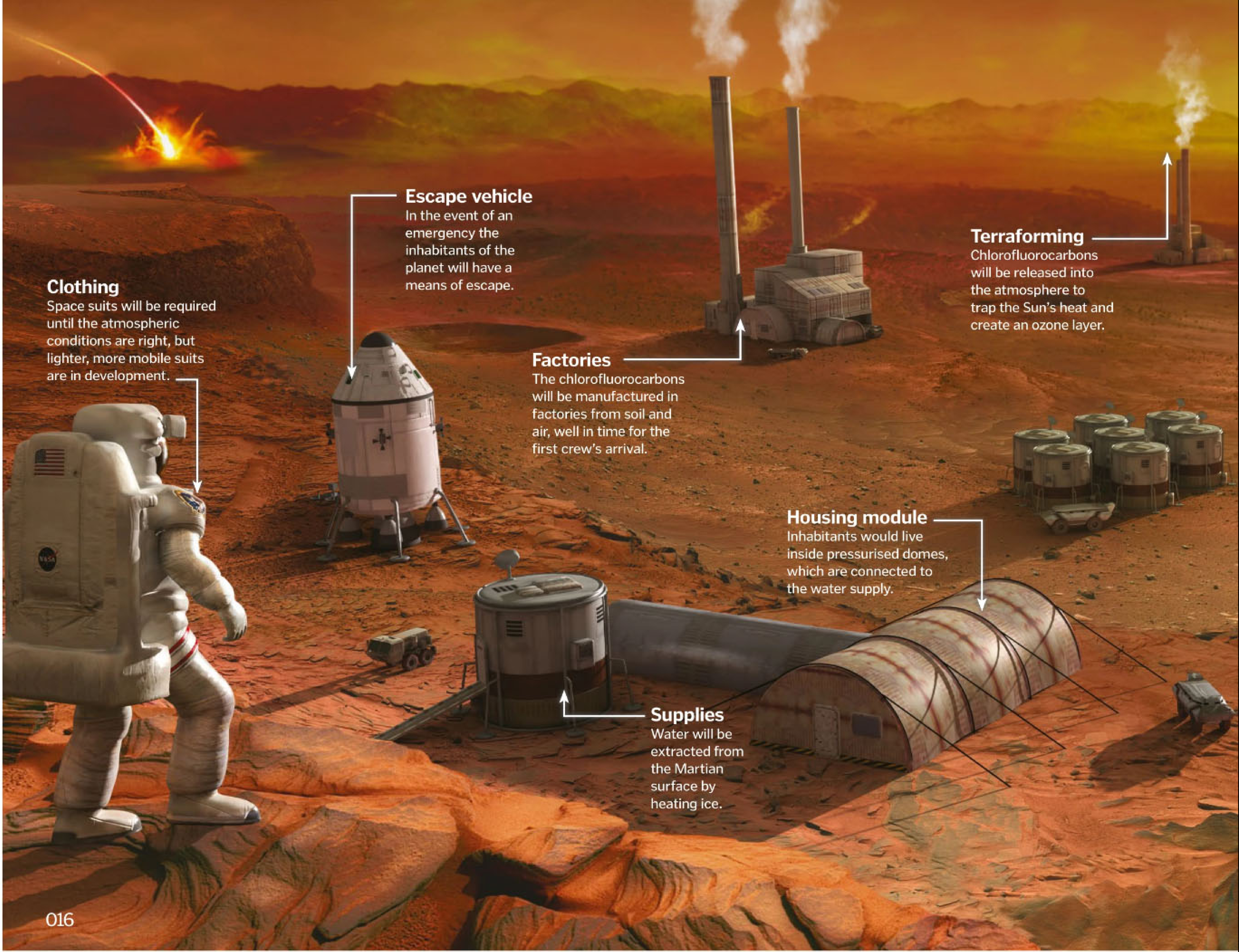
Voyager 1 has travelled just short of 20 billion kilometres (12.4 billion miles) from planet Earth, but so far, humans have only reached the Moon, which is 384,400 kilometres (239,000 miles) away. The main reasons behind the difficulty of sending humans further distances are fuel storage, costs and the comfort of the astronauts. At least one of these conditions has to be compromised for a long-distance journey into space and that has held us back.

The reaction between nano-aluminium powder and water creates a powerful blast of hydrogen gas and aluminium oxide. This provides the thrust for a rocket to launch without weighing too much. Solar technology, will also reduce the reliance on fuel, lightening the load.

MIT has developed a skintight space suit that essentially shrink-wraps the astronaut, providing counter-pressure to the atmosphere. This will be much lighter and more flexible than current space suits, making extended periods of wear much more bearable.

3D printing has paved the way for missions in space to be much more streamlined. The ability to design and print almost anything from a tiny bolt to a huge satellite dish means that missions can leave without bulky payloads on board.

All these advances in technology have pushed forward the possibility of inhabiting another planet. Mars One is a project that aims to have humans living on Mars by 2025. They hope to achieve this by sending up rovers and life-support units within the next seven years, which will seek out a location close enough to the poles for water, the equator for solar power and flat enough to build on. The life-support units will leech water from the soil by heating subsurface ice. Some will be stored and some used for creating oxygen, nitrogen and argon, to make the atmosphere breathable.



Clothing
Space suits will be required until the atmospheric conditions are right, but lighter, more mobile suits are in development.

Escape vehicle
In the event of an emergency the inhabitants of the planet will have a means of escape.

Factories
The chlorofluorocarbons will be manufactured in factories from soil and air, well in time for the first crew's arrival.

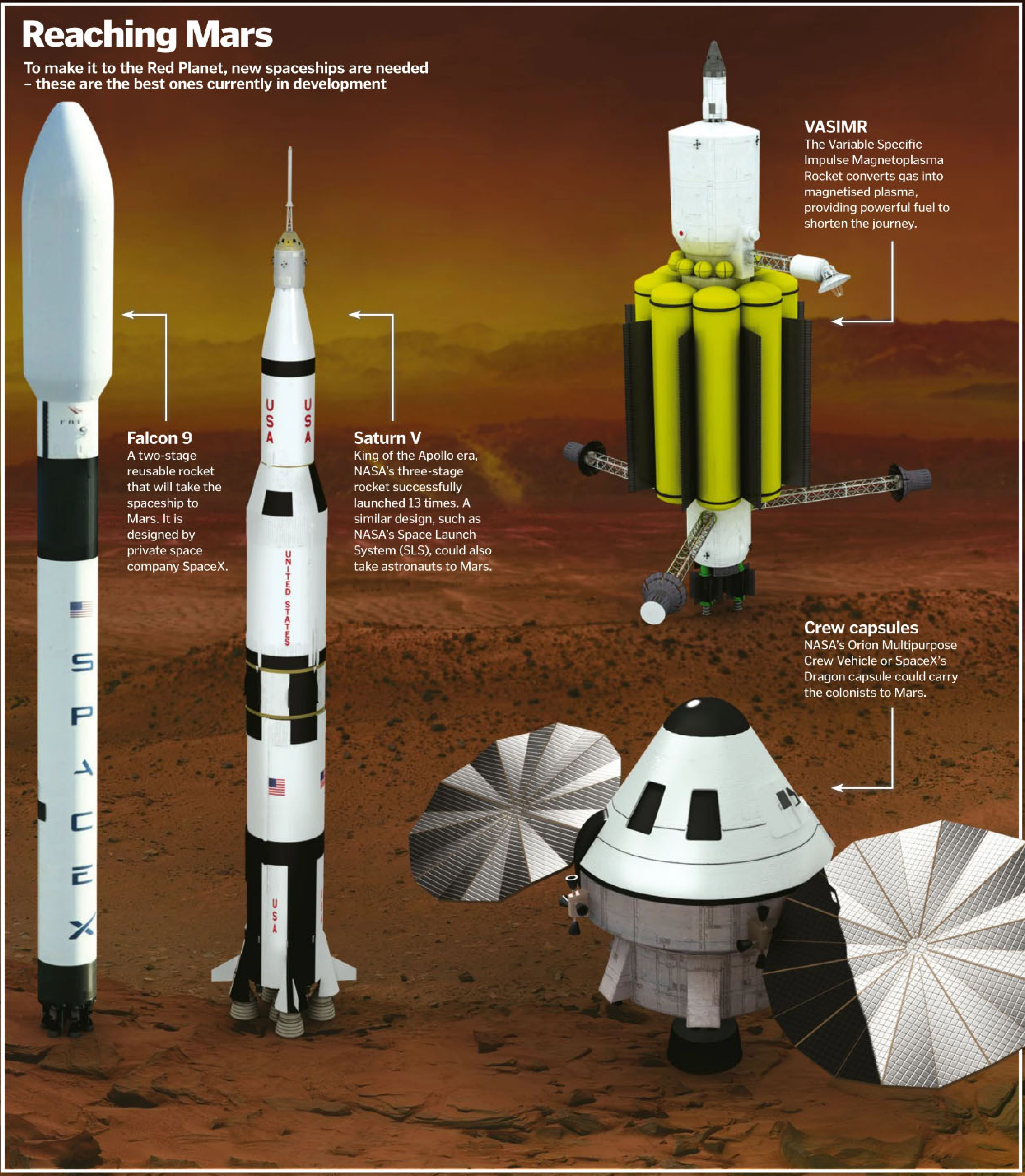
Terraforming
Chlorofluorocarbons will be released into the atmosphere to trap the Sun's heat and create an ozone layer.

Housing module
Inhabitants would live inside pressurised domes, which are connected to the water supply.

Supplies
Water will be extracted from the Martian surface by heating ice.

Reaching Mars

To make it to the Red Planet, new spaceships are needed – these are the best ones currently in development



Falcon 9
A two-stage reusable rocket that will take the spaceship to Mars. It is designed by private space company SpaceX.

Saturn V
King of the Apollo era, NASA's three-stage rocket successfully launched 13 times. A similar design, such as NASA's Space Launch System (SLS), could also take astronauts to Mars.

VASIMR
The Variable Specific Impulse Magnetoplasma Rocket converts gas into magnetised plasma, providing powerful fuel to shorten the journey.

Crew capsules
NASA's Orion Multipurpose Crew Vehicle or SpaceX's Dragon capsule could carry the colonists to Mars.

© Solgo; Dreamstime

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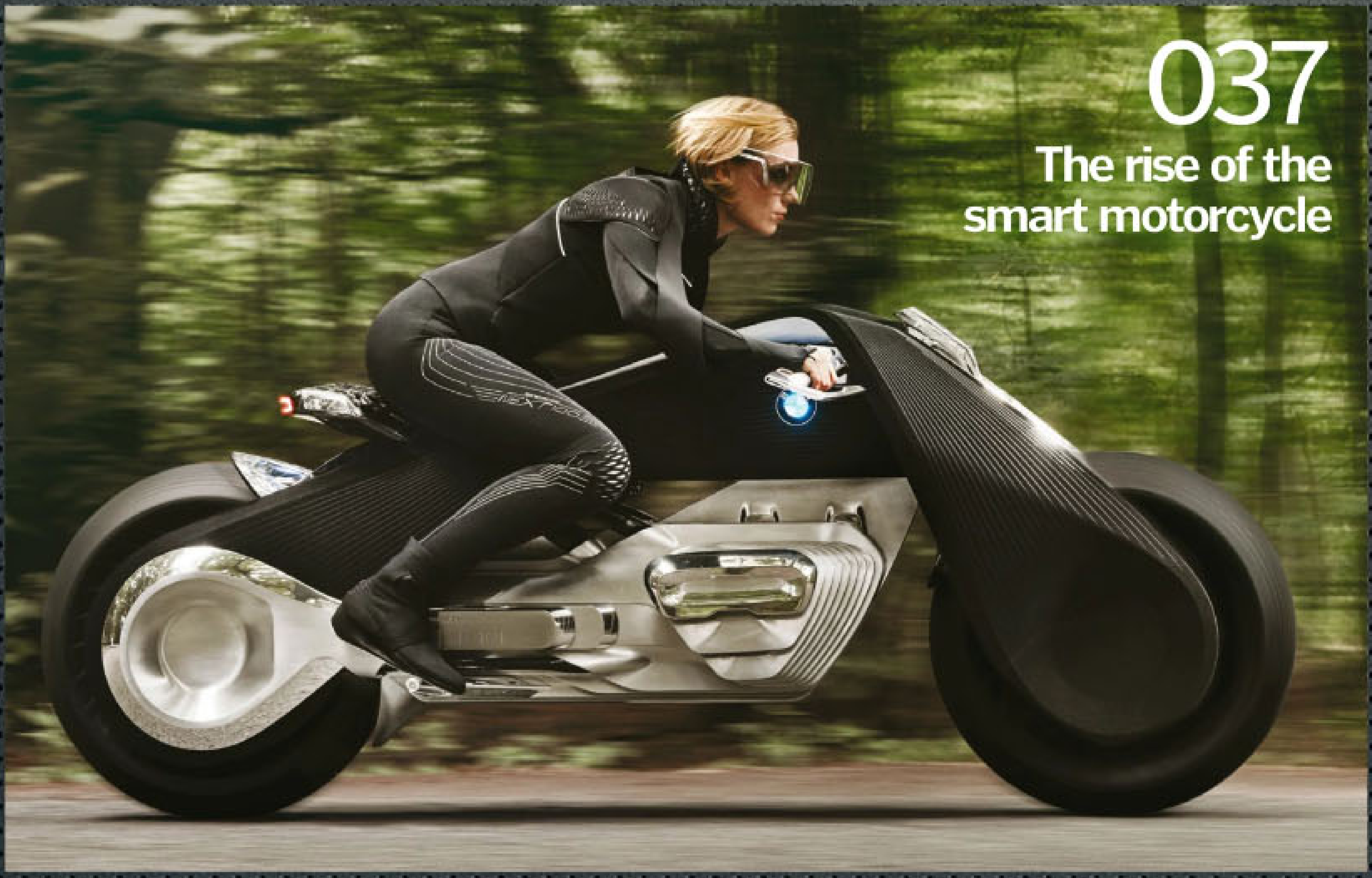

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Get your own submarine

5 TIMES THE SPEED OF SOUND

HYPERSONIC FLIGHT

Inside the planes that will smash supersonic records

Blink and you'll miss them, but you'll definitely hear them. Hypersonic aircraft may look similar to the jet planes we're familiar with, but these engineering marvels are completely different beasts. Able to attain speeds that would literally tear a conventional passenger jet apart, hypersonic aircraft possess unique engines, are built from advanced materials and are packed full of intelligent tech.

So just how fast are they? By definition, a supersonic vehicle can move faster than the speed of sound – or Mach 1 – which is 1,235 kilometres per hour, or 343 metres per second. But to be classed as hypersonic, planes must fly at least five times this speed – 6,175 kilometres per hour, or 1,715 metres per second. And their speed isn't limited to Mach 5; that's just the beginning. We've already created aircraft that can reach Mach 20 – that's nearly seven kilometres per second! As long as these vehicles can withstand the pressure in the atmosphere, they can keep moving faster and faster.

For over 30 years we were able to use Concorde to fly at supersonic speeds. It broke through the sound barrier and revolutionised air travel. But now the aim is to go faster than ever, with jets and commercial airliners capable of reaching even greater speeds. This is, of course, no simple task, but little over a century after the Wright brothers first took to the skies, we're still building new and innovative aircraft. This technology reveals new realms of possibility that would make air travel more efficient and convenient than ever before. Imagine travelling halfway around the world in just a few hours, or seeing a spacecraft climb into the upper atmosphere without a gigantic rocket.

The most exciting part is that this isn't the stuff of science fiction – we've already flown vehicles at hypersonic speeds, and researchers are now developing hypersonic planes suitable for public use. Read on for more of these incredible feats of engineering and the faster world that awaits us.

> "Hypersonic aircraft attain speeds that would tear a conventional passenger jet apart"

Hypersonic vs supersonic

For many years experts believed it was simply impossible to fly faster than the speed of sound. But that all changed in the 1940s, when US test pilot Chuck Yeager flew faster than Mach 1 – the speed of sound – for the first time in human history.

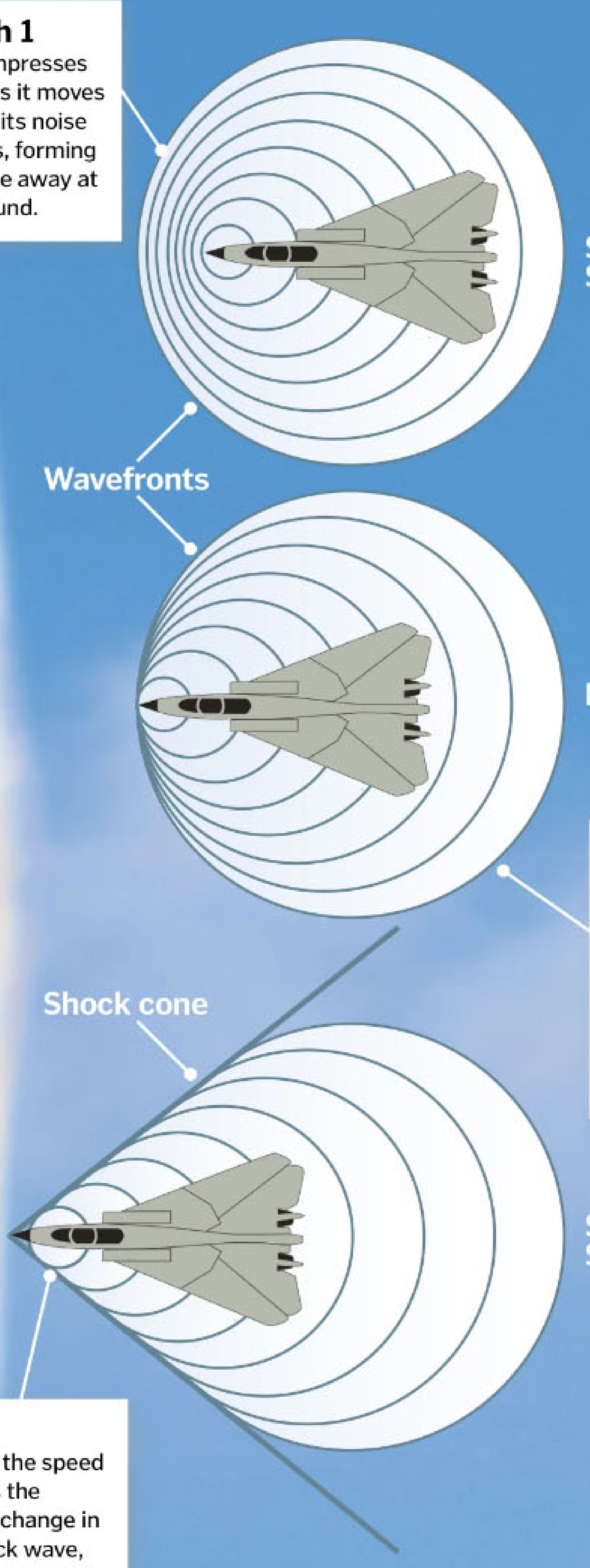
Onlookers below heard the sonic boom as the pressurised air gave way to the Bell X-1 rocket plane, and they realised that supersonic aircraft were dealing with new extremes.

But although supersonic aircraft have to overcome many obstacles to break the sound barrier, these factors are compounded when moving at hypersonic speeds. At Mach 5 and above, the air does more than just form shock waves. At such high speeds, the air heats the surface of the aircraft to very high temperatures – enough to melt steel – and the engines have to cope with huge pressures.

What causes a sonic boom?

Why breaking through the sound barrier is such a noisy affair

Continuous boom
An aircraft travelling faster than Mach 1 is constantly producing shock waves, which merge to form a cone. In certain conditions, this is visible as a conical cloud of water vapour.



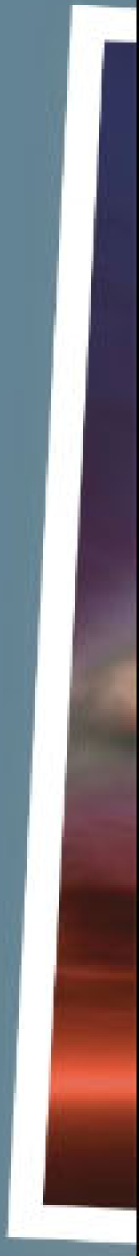
Below Mach 1
The aircraft compresses the air in front as it moves forward and emits noise from its engines, forming waves that move away at the speed of sound.

At Mach 1
When the aircraft reaches the speed of sound, the air being compressed cannot move away fast enough, so the waves accumulate at the nose of the plane.

Above Mach 1
As the plane exceeds the speed of sound, it overtakes the waves. This causes a change in air pressure, or a shock wave, which is heard as a sonic boom.

Around 75 passengers could be transported at Mach 10 inside the Skreemr

© Thinkstock; Imaginactive.org / Ray Mattison; Oscar Vinals



BUILDING A HYPERSONIC VEHICLE

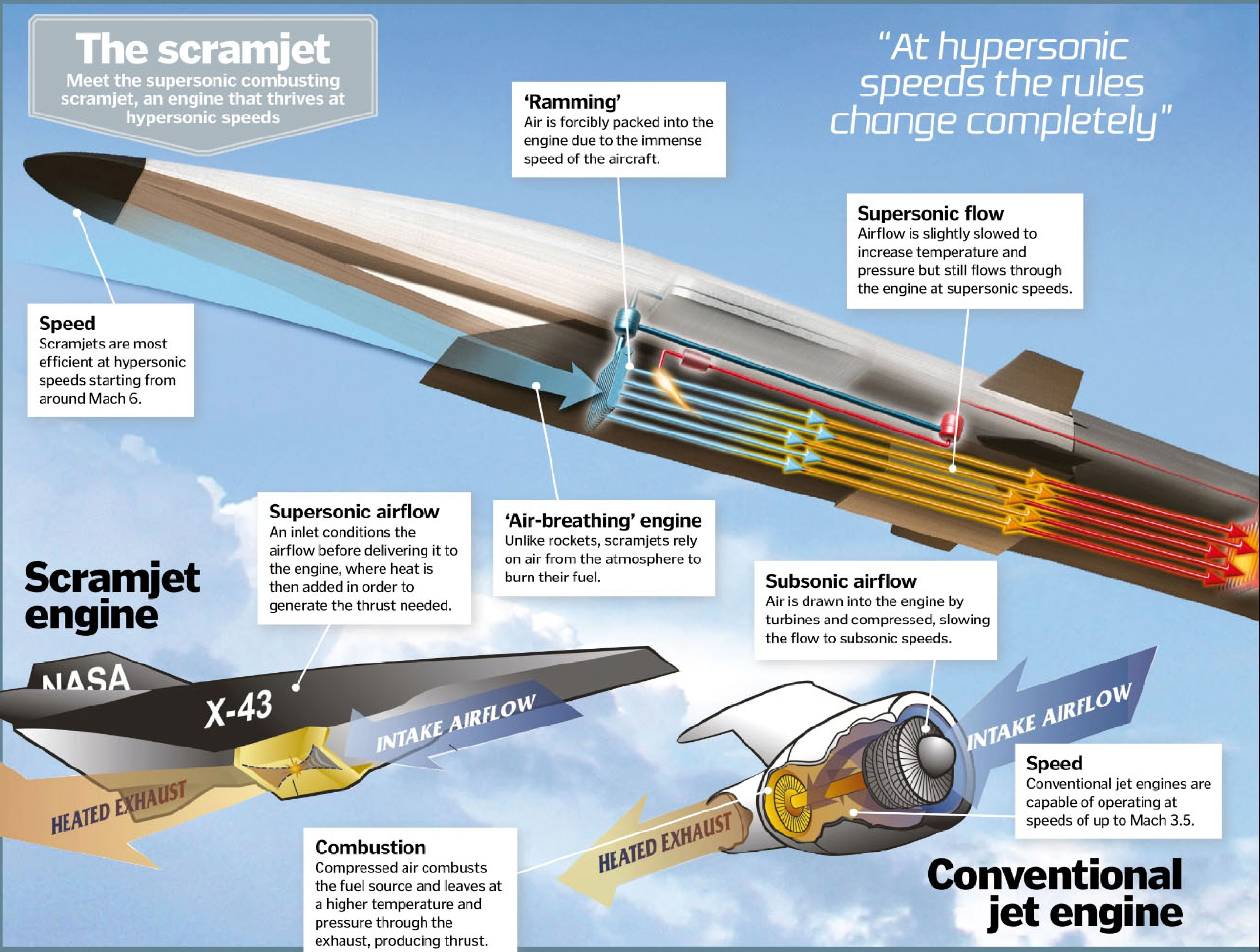
The challenges and successes in the engineering community's quest for hypersonic flight

Supersonic aircraft such as Concorde differed greatly from their subsonic counterparts. They had adapted wing designs and advanced engines. These changes allowed Concorde to smash through the sound barrier, which is something subsonic commercial jets were simply unable to do.

The difference between a supersonic and a hypersonic aircraft is even more striking, because at hypersonic speeds the rules change completely. The previously benign air starts to become a serious problem, as aircraft moving at hypersonic speed generate huge amounts of friction. This results in temperatures hot enough to melt the frame of a standard jet, so hypersonic aircraft must be built from robust heat-resistant materials such as ceramics. And they can't stop there, because even if they are able to withstand the heat, the pressure at low altitudes is simply too great to fly at hypersonic speeds. Hypersonic vehicles need to climb high up into the atmosphere, where the air is much thinner, in order to lessen the strain on the aircraft.

Perhaps the biggest consequence of the intense airflow is that hypersonic vehicles can't even use the same engines as subsonic aircraft. Air moving through supersonic plane engines does so at subsonic speeds (the supersonic airflow is slowed by an engine inlet), but if you tried using a similar setup when travelling at hypersonic speeds, it would melt or simply explode before your eyes. But rather than rely on rocket engines – the only proven systems to power hypersonic vehicles – engineers asked themselves a more ambitious question: could we take what we've learned about the jet engine and design an equivalent that works at high supersonic, and even hypersonic, speeds?

This led to the invention of the supersonic combustible ramjet, or scramjet. Taking the principles of a jet engine and stripping away all of the unnecessary components for hypersonic travel – such as a turbine and a compressor – allows air to move through much more quickly. With few moving parts, these simple-looking engines produce enough thrust for an aircraft to soar at incredible speeds; and in doing so, have started to bring the future of air travel to life.



The scramjet

Meet the supersonic combusting scramjet, an engine that thrives at hypersonic speeds

"At hypersonic speeds the rules change completely"

'Ramming'
Air is forcibly packed into the engine due to the immense speed of the aircraft.

Supersonic flow
Airflow is slightly slowed to increase temperature and pressure but still flows through the engine at supersonic speeds.

Speed
Scramjets are most efficient at hypersonic speeds starting from around Mach 6.

Supersonic airflow
An inlet conditions the airflow before delivering it to the engine, where heat is then added in order to generate the thrust needed.

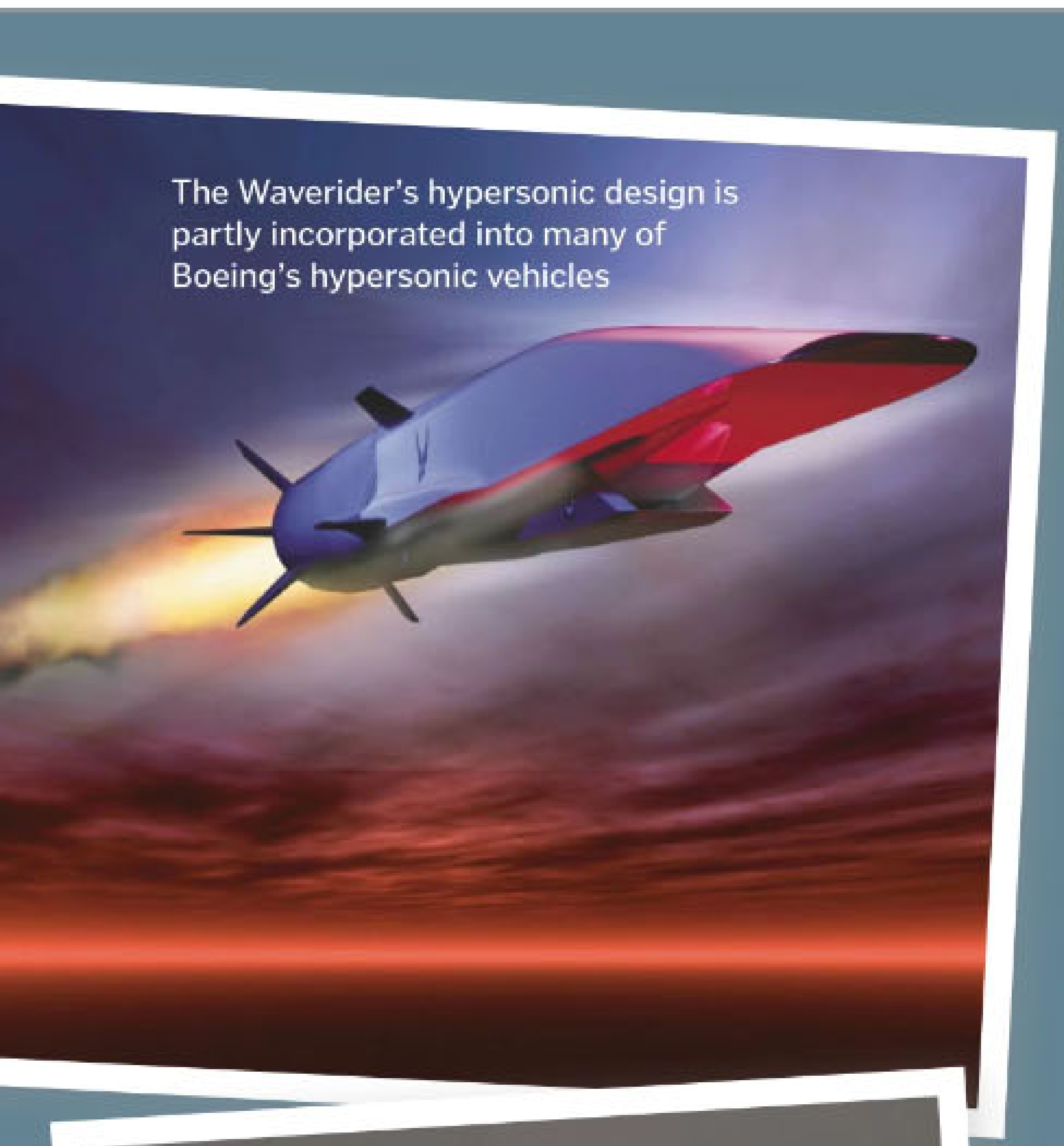
'Air-breathing' engine
Unlike rockets, scramjets rely on air from the atmosphere to burn their fuel.

Subsonic airflow
Air is drawn into the engine by turbines and compressed, slowing the flow to subsonic speeds.

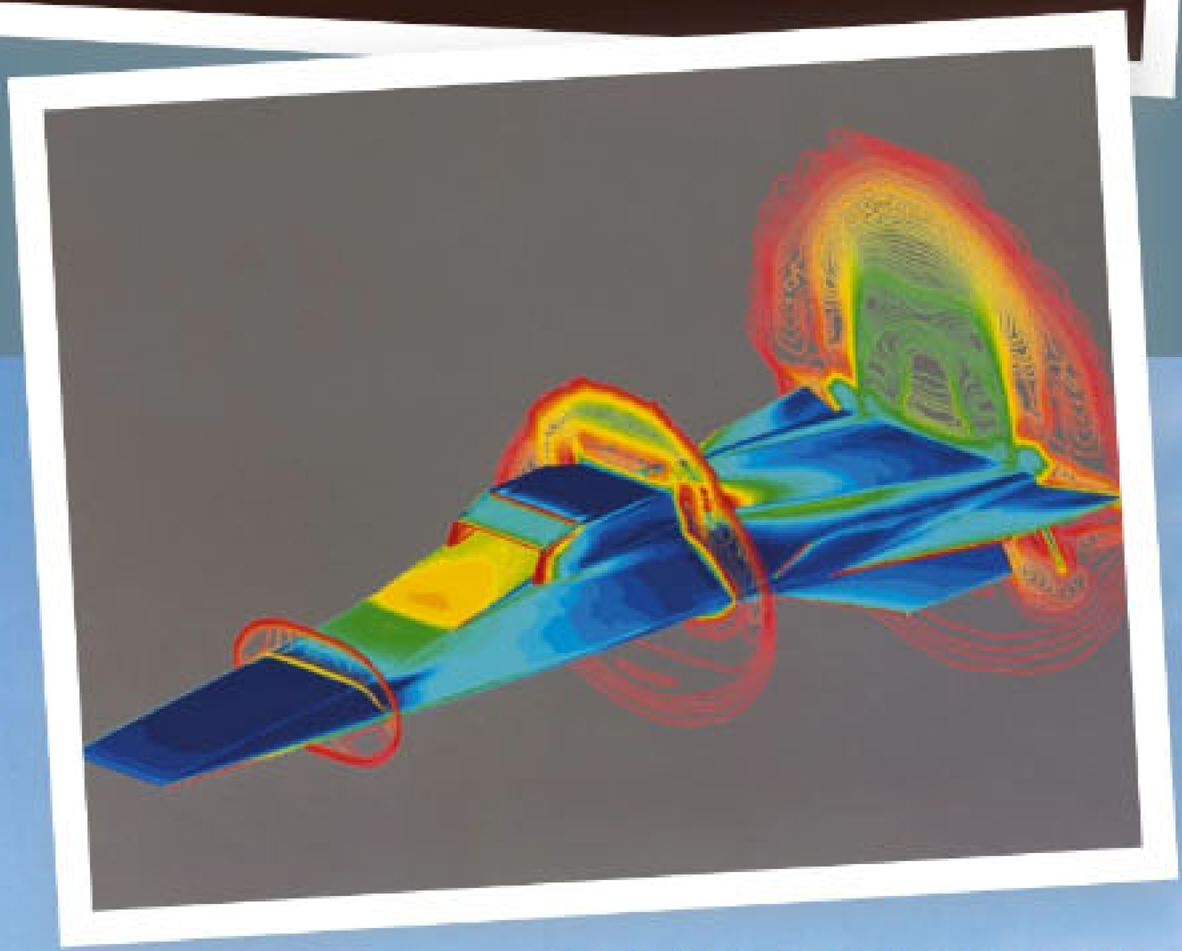
Speed
Conventional jet engines are capable of operating at speeds of up to Mach 3.5.

Combustion
Compressed air combusts the fuel source and leaves at a higher temperature and pressure through the exhaust, producing thrust.

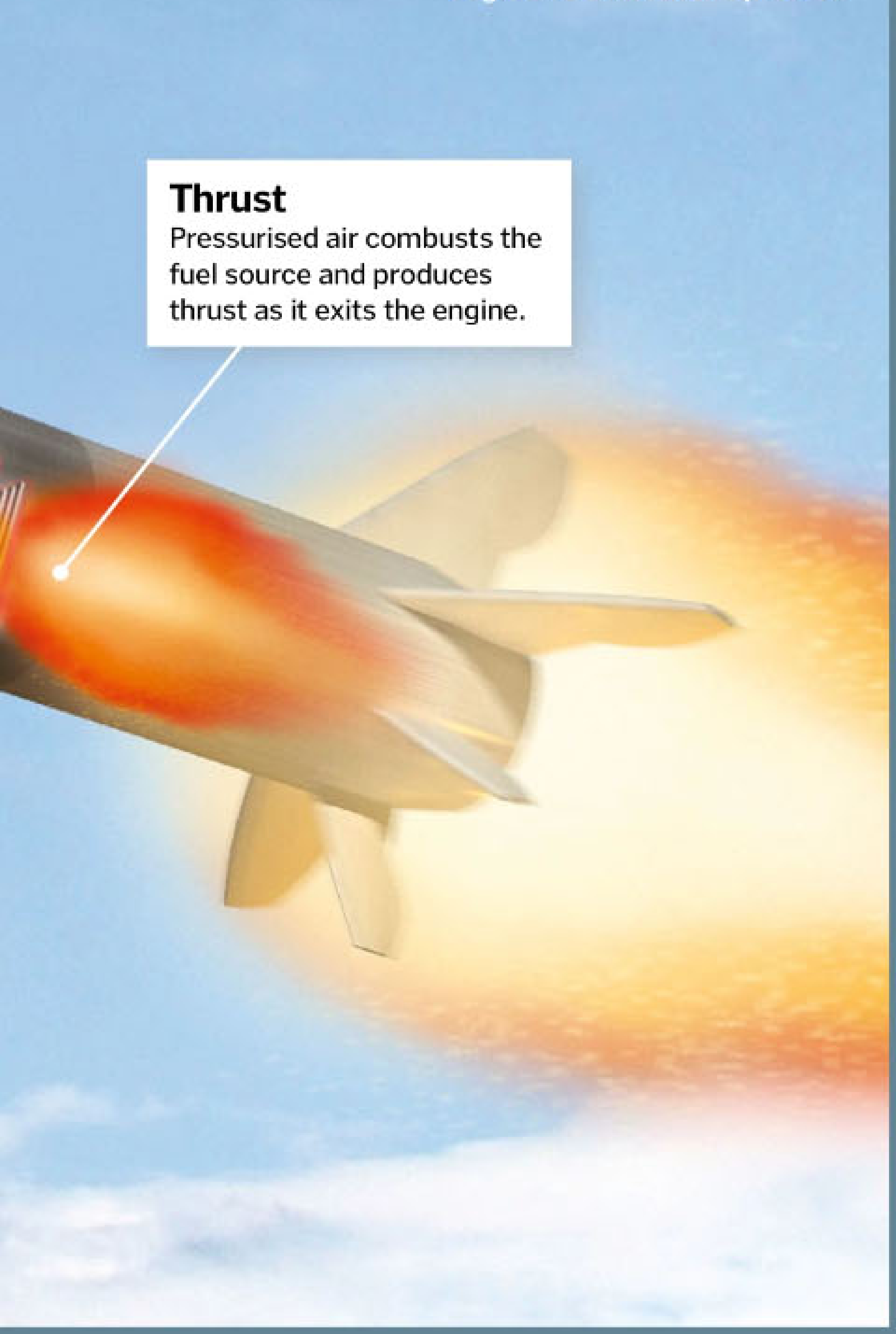
DID YOU KNOW? *A hypersonic vehicle would experience 492,000kg/m² of pressure if flown at ground level*



The Waverider's hypersonic design is partly incorporated into many of Boeing's hypersonic vehicles



The X-43 was the first aircraft to travel at Mach 7, enduring 1,650 degrees Celsius in the process



Thrust
Pressurised air combusts the fuel source and produces thrust as it exits the engine.

MAKING HYPERSONIC FLIGHT A REALITY

We spoke with Boeing's chief scientist of hypersonics, Dr Kevin Bowcutt, about the future of high-speed travel

Dr Kevin Bowcutt is the senior technical fellow and chief scientist of hypersonics at Boeing. He is an AIAA Fellow, a Fellow of the Royal Aeronautical Society, and also a member of the National Academy of Engineering. He holds BS, MS and PhD degrees in aerospace engineering from the University of Maryland, US.

Why is Boeing so interested in hypersonic technology?

Boeing is interested in hypersonic technology for several reasons, including application to missiles, aircraft, and space planes. Hypersonic airplanes may someday whisk passengers and cargo across oceans in an hour or two, enabling international day trips. Perhaps most exciting of all, reusable hypersonic space planes may make transportation to Earth's orbit more like flying in an airplane than a rocket, and therefore much more affordable – up to 100-times cheaper.

What hypersonic technologies are you currently developing?

Key enablers to make hypersonic flight a reality include lighter and more durable high-temperature materials, increased hypersonic engine efficiency, and advanced sensing and data analysis technologies. On the technology front we are developing advanced high-temperature ceramic matrix composite materials, structures, and thermal protection systems. We are also developing, and have applied, advanced hypersonic vehicle design methods based on multidisciplinary design analysis and optimisation (MDAO). We have designed, and continue to study, hypersonic vehicle concepts such as missiles, reconnaissance aircraft, passenger airplanes, and reusable launch vehicles (space planes). We have built and successfully flown two scramjet-powered experimental vehicles, the NASA X-43A and the USAF/DARPA X-51A.

What are the main challenges you currently face?

Finding materials that withstand very high temperature, and that are lightweight and durable, remains a challenge, although good progress is being made in their development. Scaling up scramjets to larger sizes (beyond small jet engine size in terms of air flow rate) and speeds above Mach 7 is another difficulty due to ground testing limitations. Integrating low-speed and high-speed propulsion systems into combined cycle engines is another area for further development; combined cycle engines are required to accelerate from zero to hypersonic speed. Additional challenges include vehicle thermal management and thermo-structural health monitoring, as well as designing highly integrated systems such as hypersonic vehicles, driving the need for MDAO. On top of this, adequate funding is a perennial problem, although the situation is improving.

What is the overall goal of your project?

While Boeing is not developing a hypersonic airliner, and does not see a near-term demand for the product, we continue to research many advanced hypersonic concepts and technologies, so that we are prepared if the market develops for such vehicles. The potential for hypersonic aircraft in the future will require further advances in several areas of technology, as well as market demand. Ultimately, we want to help create the future of flight: ultra-rapid global transportation and routine and affordable space access.

How do you picture the future of hypersonic flight?

Although it's likely to be a few decades away, I envision a future where Mach 5 airplanes fly people between international cities in a couple of hours, and space planes routinely fly people to a hub in Earth's orbit for connecting flights to the Moon or Mars. Eventually, these vehicles will be powered by clean, high-density energy, probably some form of safe nuclear power.

© SPL; Alamy; US Air Force

THE FUTURE OF HYPERSONIC FLIGHT

Exploring the concepts that could one day replace the jet plane

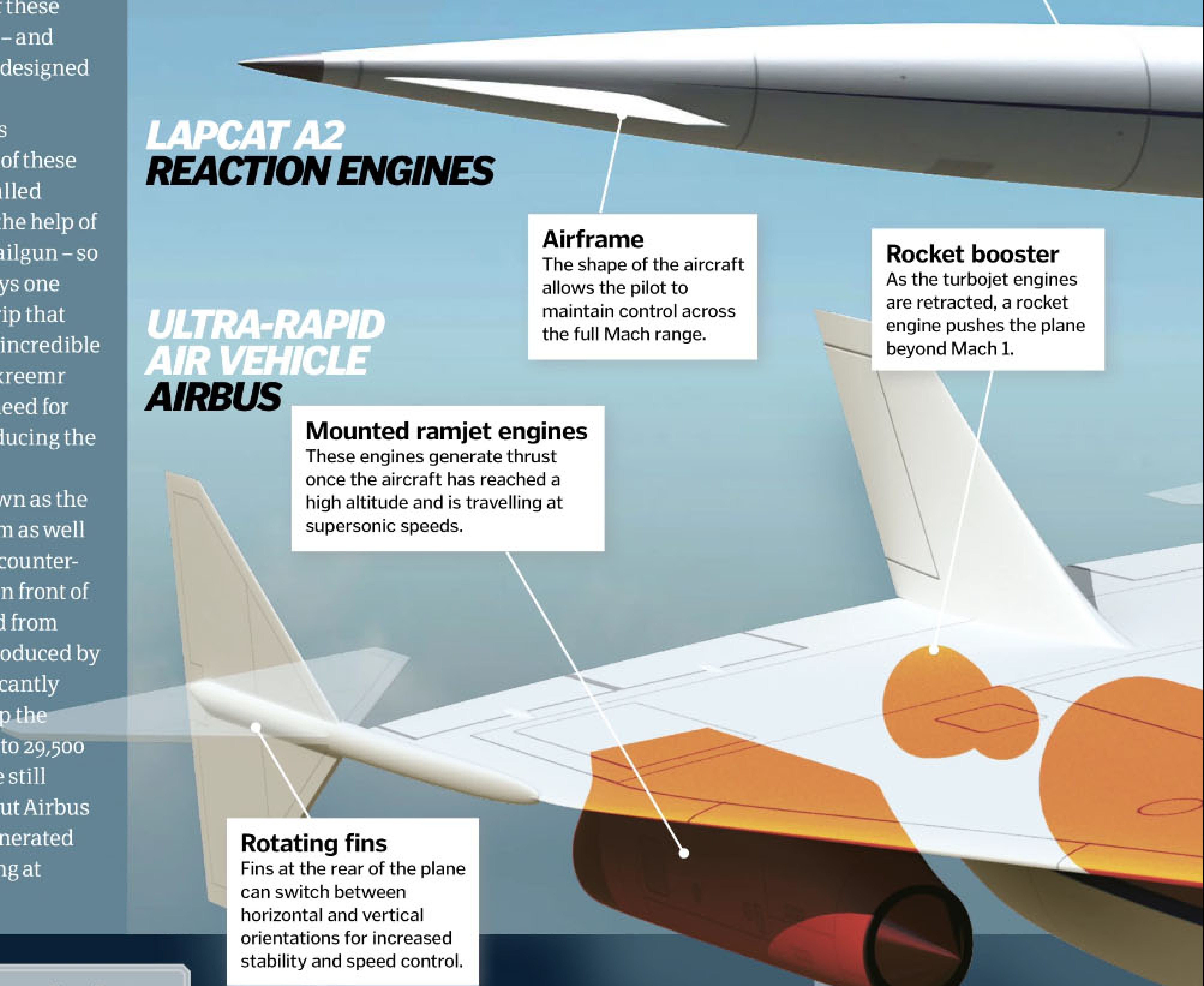
If there's one lesson that we've learned about hypersonic flight so far, it's that heat, weight and power are all major obstacles. Too much weight, and you can't reach the desired speed. Too much heat, and your aircraft will melt mid-flight. And then there's the question of how we can power our machine to hypersonic speeds and keep it there. Fortunately, solutions for each of these critical problems have been suggested – and some seriously cool aircraft have been designed in the process.

Innovative engineers such as Charles Bombardier have been at the forefront of these endeavours. His envisioned aircraft, called Skreemr, would take to the skies with the help of an electrical launch system such as a railgun – so we could be bidding farewell to runways one day. A railgun is an electromagnetic strip that uses electricity to launch projectiles at incredible speeds, and could be used to fire the Skreemr into the air. This would eliminate the need for tons of extra rocket fuel for take-off, reducing the aircraft's weight considerably.

Another design by Bombardier, known as the Antipode, could tackle the heat problem as well as the menacing sonic boom. By using counter-flowing jets of air that move outwards in front of the aircraft, the temperature generated from aerodynamic friction and the sound produced by the sonic shock waves would be significantly reduced. And these features would help the Antipode fly up to Mach 24, equivalent to 29,500 kilometres per hour! These designs are still some time away from being realised, but Airbus and Reaction Engines have recently generated two concepts that could have us cruising at hypersonic speeds that much sooner.

Hypersonic hopefuls

Rival aerospace engineers are tackling the same mission in two very different ways



LAPCAT A2
REACTION ENGINES

ULTRA-RAPID AIR VEHICLE
AIRBUS

Passengers
Up to 300 passengers plus baggage can be transported, ensuring ticket prices remain competitive with those of subsonic airliners.

Airframe
The shape of the aircraft allows the pilot to maintain control across the full Mach range.

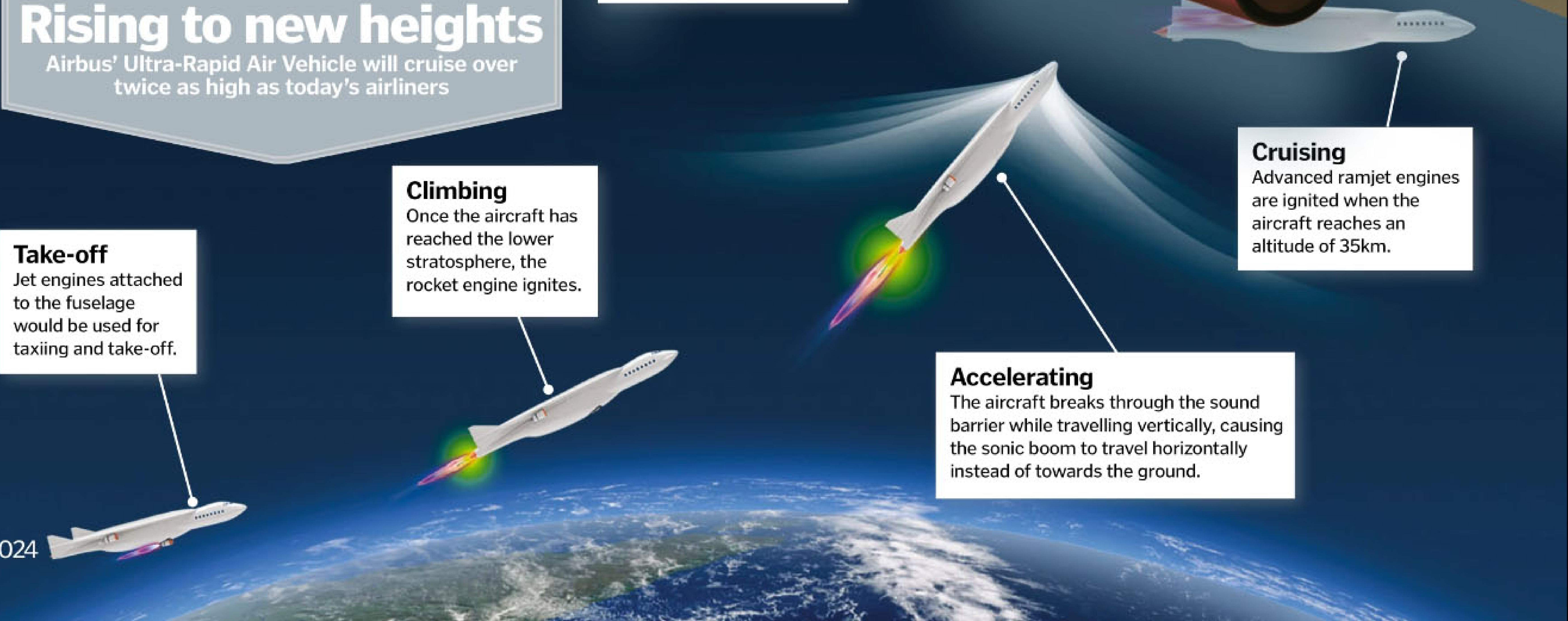
Rocket booster
As the turbojet engines are retracted, a rocket engine pushes the plane beyond Mach 1.

Mounted ramjet engines
These engines generate thrust once the aircraft has reached a high altitude and is travelling at supersonic speeds.

Rotating fins
Fins at the rear of the plane can switch between horizontal and vertical orientations for increased stability and speed control.

Rising to new heights

Airbus' Ultra-Rapid Air Vehicle will cruise over twice as high as today's airliners



Take-off
Jet engines attached to the fuselage would be used for taxiing and take-off.

Climbing
Once the aircraft has reached the lower stratosphere, the rocket engine ignites.

Accelerating
The aircraft breaks through the sound barrier while travelling vertically, causing the sonic boom to travel horizontally instead of towards the ground.

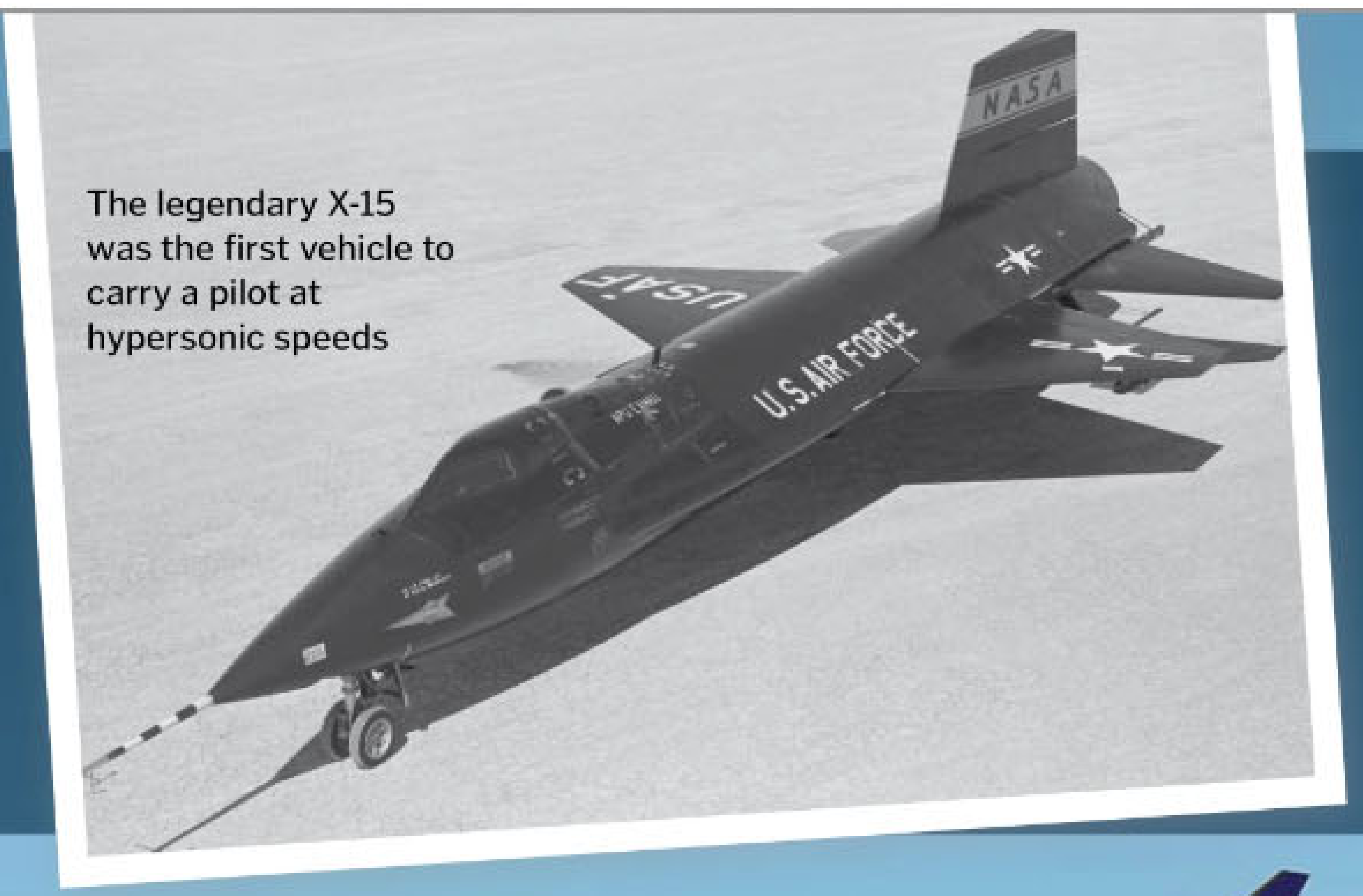
Cruising
Advanced ramjet engines are ignited when the aircraft reaches an altitude of 35km.

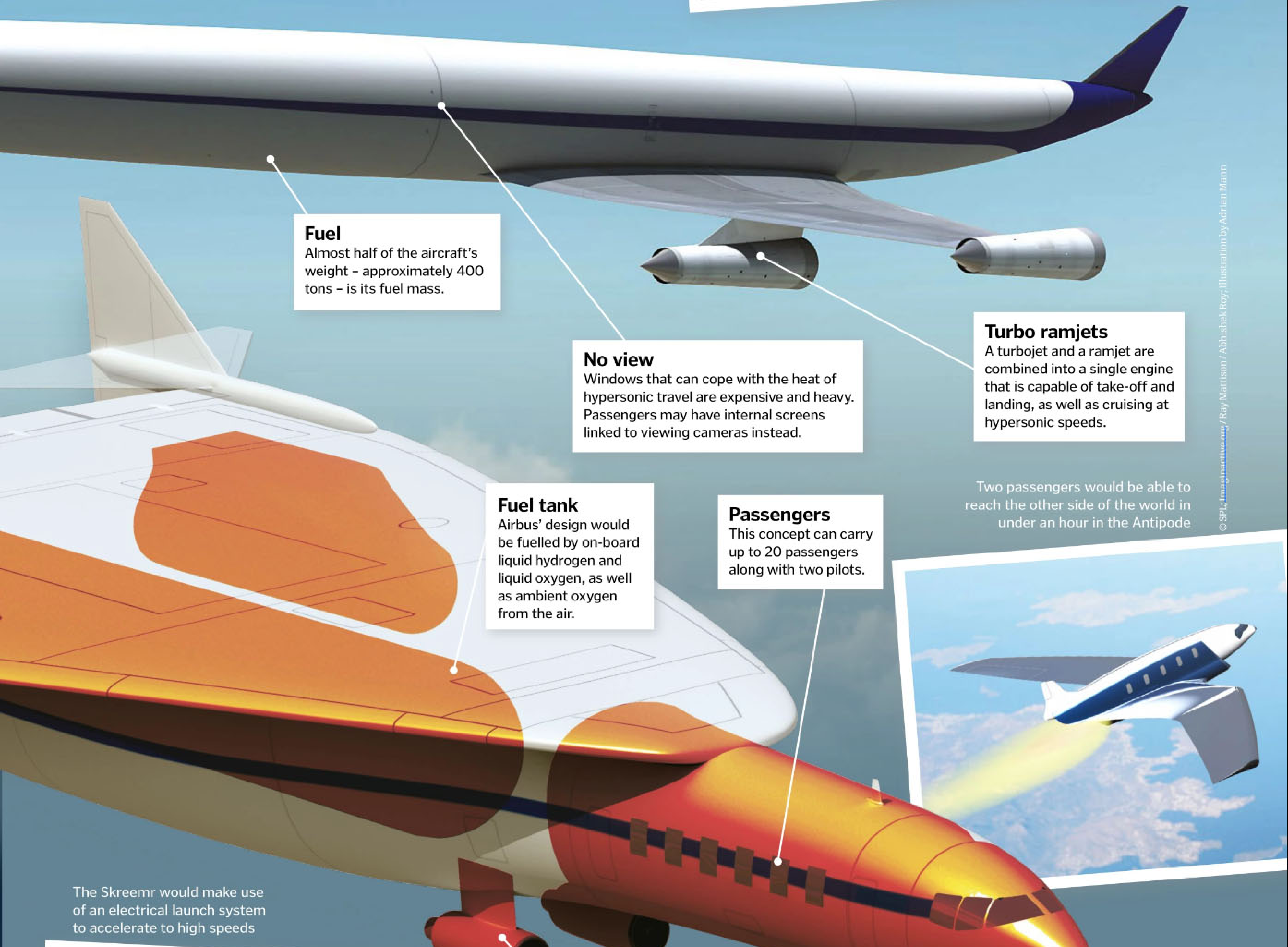
DID YOU KNOW? *Liquid hydrogen fuel, which most hypersonic aircraft will use, is much safer than conventional kerosene fuel*

The history of hypersonic travel

It's been 60 years since a piloted vehicle first travelled faster than Mach 5, breaking the hypersonic barrier in a defining moment that showed the true possibility of space travel. The X-15 aircraft not only showed us that we could be carried at hypersonic speed, but taught us about how best to design, control and safely land a vehicle capable of achieving such a feat. The aircraft itself was essentially a rocket/plane hybrid, built to endure temperatures up to 700 degrees Celsius and fly at an altitude of over 100 kilometres, while being blasted through the air by a rocket engine at the rear.

Its achievements filled its creators with confidence that they could soon launch a vehicle into space at high speeds and bring it back into the atmosphere safely. Essentially, the X-15 played a role in putting humans on the Moon.


The legendary X-15 was the first vehicle to carry a pilot at hypersonic speeds



Fuel
Almost half of the aircraft's weight – approximately 400 tons – is its fuel mass.

No view
Windows that can cope with the heat of hypersonic travel are expensive and heavy. Passengers may have internal screens linked to viewing cameras instead.

Turbo ramjets
A turbojet and a ramjet are combined into a single engine that is capable of take-off and landing, as well as cruising at hypersonic speeds.

Fuel tank
Airbus' design would be fuelled by on-board liquid hydrogen and liquid oxygen, as well as ambient oxygen from the air.

Passengers
This concept can carry up to 20 passengers along with two pilots.

Retractable turbojet engines
Conventional engines are used during take-off and are then withdrawn into the fuselage, making the vehicle more streamlined.

Two passengers would be able to reach the other side of the world in under an hour in the Antipode

The Skreemr would make use of an electrical launch system to accelerate to high speeds

"We could be bidding farewell to runways one day"

© SPL; Imaginactive.org / Ray Mattison / Abhishek Roy; Illustration by Adrian Mann

HIGH-SPEED HOLIDAYS

It may soon be possible to watch the Sun rise in Paris and set in Tokyo

Most of us see travelling to the other side of the globe as the trip of a lifetime. Aside from the expense, these journeys take a very long time indeed. When we have to watch hours upon hours of in-flight entertainment on long-haul flights, it feels like we're lumbering through the air.

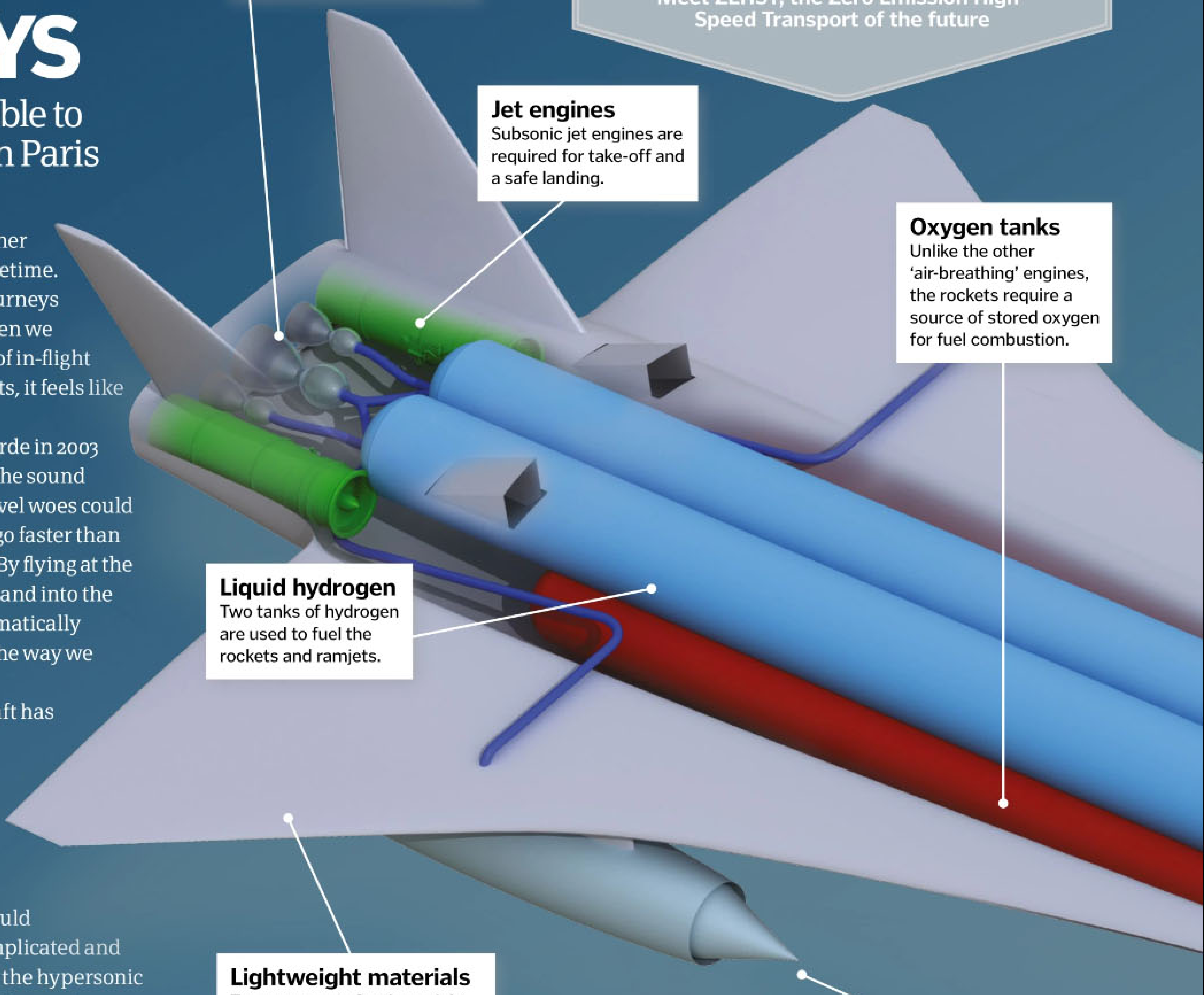
Ever since the world lost Concorde in 2003 we've been content to fly within the sound barrier. But the answer to our travel woes could be to punch right through it and go faster than any passenger plane has before. By flying at the upper limits of supersonic speed and into the hypersonic region, we could dramatically reduce travel times and change the way we explore the world.

The unique design of the aircraft has become the main challenge for revolutionising air travel. Most passengers probably wouldn't be comfortable strapping into a rocket and blasting across the planet. Using a rocket for international travel would also be infeasibly expensive, complicated and bad for the environment. Ideally, the hypersonic passenger carrier of the future will operate much like today's subsonic airliners. Passengers would be able to take their seats in a pressurised cabin, and the vehicle would be able to take-off and land unaided on a conventional runway.

Engineers have decided that using multiple engine types is the way to get this technology off the ground. Typical jet engines could be used for take-off and landing; a rocket engine could then propel us to great heights and speeds; and then the supersonic or hypersonic engine could take over. This would nevertheless be something of a thrill ride, as some designers believe their aircraft would have to take off near vertically! Those of us with a nervous disposition to flying may find it best to stick to the relatively sluggish speeds of a jumbo jet. However, for those holidaymakers and businesspeople who want to maximise the time spent at their destinations, and are willing to brave a vertical ascent into the atmosphere, hypersonic journeys will be the way forward.

Taking tourists to the upper stratosphere

Meet ZEHST, the Zero Emission High-Speed Transport of the future



Rocket power
Rockets take over from the jet engines after take-off to increase the aircraft's speed to at least Mach 2.5.

Jet engines
Subsonic jet engines are required for take-off and a safe landing.

Oxygen tanks
Unlike the other 'air-breathing' engines, the rockets require a source of stored oxygen for fuel combustion.

Liquid hydrogen
Two tanks of hydrogen are used to fuel the rockets and ramjets.

Lightweight materials
To compensate for the weight of multiple engines, the frame must be lightweight yet strong enough to endure high levels of aerodynamic drag.

Ramjets
When the aircraft's speed reaches 3,100km/h, air can be 'rammed' through the ramjets fast enough for the engines to produce thrust.

It would take a hypersonic vehicle only an hour and a half to travel from London to Cape Town

A hypersonic vehicle could get you from London to Sydney in less than three hours

DID YOU KNOW? Travelling at Mach 5, you could circumnavigate the globe in less than seven hours

Suppressing the sonic boom

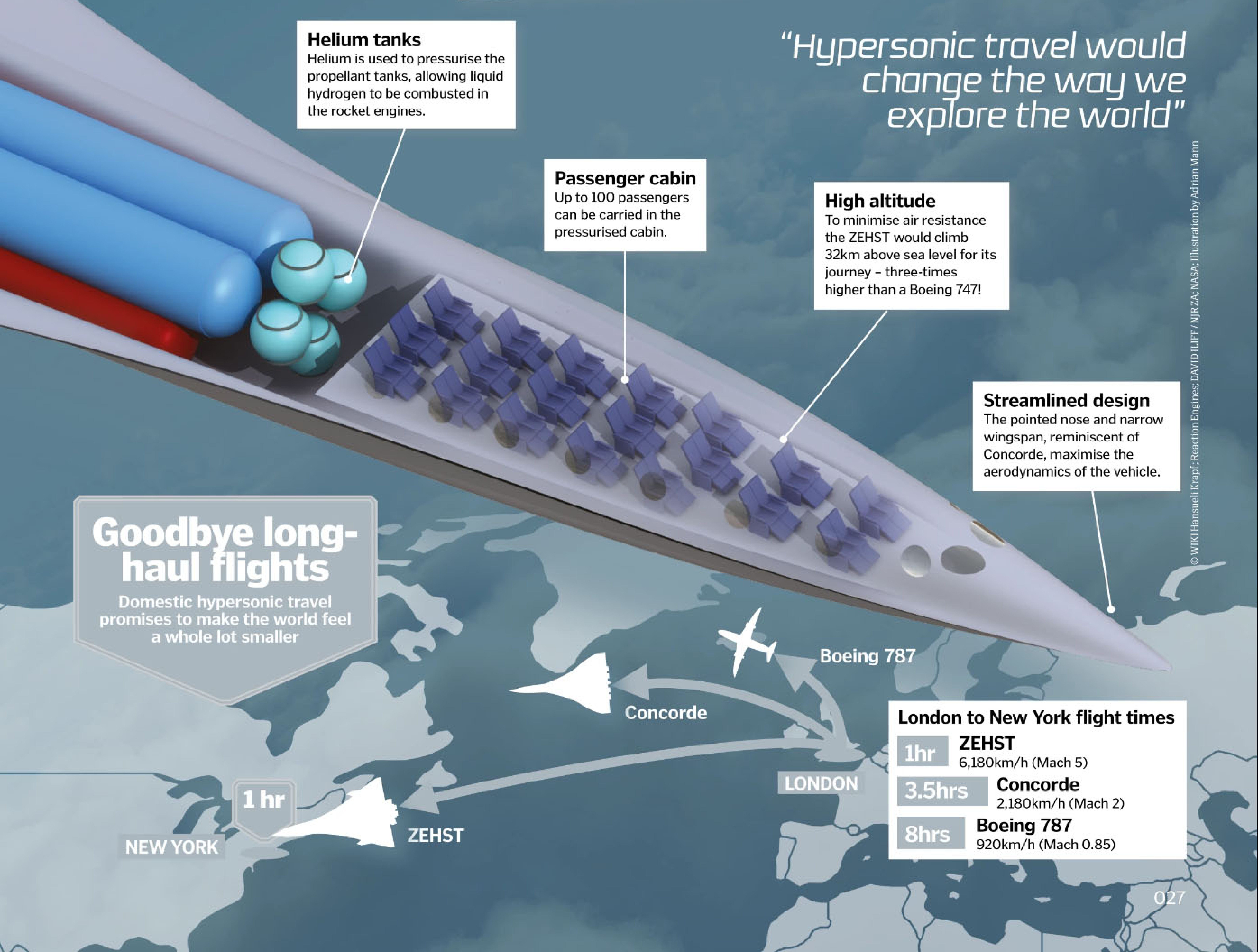
Whether you're going supersonic or hypersonic, breaking the sound barrier is loud. As a vehicle accelerates, the waves of air pressure being pushed along by the frame begin to merge into one single shock wave. This air can travel at the speed of sound but as a vehicle surpasses this speed, a drastic change in pressure results in a deafening clap – a sonic boom.

The sonic boom is one major hurdle for aviation companies to overcome if hypersonic flight is going to be made available commercially. Concorde – the first and only public transport to break the sound barrier – was criticised for its volume and was only permitted to break the sound barrier over the ocean.

Like many aerospace issues, it could be NASA that comes to the rescue once again. The space agency and its partners at Lockheed Martin are in the process of designing an aircraft with many lifting surfaces to stop the airwaves from combining. The result would be a series of small booms rather than one big one – lowering the sound output to that of a normal conversation.

NASA and Lockheed Martin's Quiet Supersonic Technology (QueSST) X-plane design will be a step towards 'low-boom' supersonic travel

> *"Hypersonic travel would change the way we explore the world"*



Helium tanks
Helium is used to pressurise the propellant tanks, allowing liquid hydrogen to be combusted in the rocket engines.

Passenger cabin
Up to 100 passengers can be carried in the pressurised cabin.

High altitude
To minimise air resistance the ZEHST would climb 32km above sea level for its journey – three-times higher than a Boeing 747!

Streamlined design
The pointed nose and narrow wingspan, reminiscent of Concorde, maximise the aerodynamics of the vehicle.

Goodbye long-haul flights

Domestic hypersonic travel promises to make the world feel a whole lot smaller

London to New York flight times

1hr	**ZEHST**	6,180km/h (Mach 5)
3.5hrs	**Concorde**	2,180km/h (Mach 2)
8hrs	**Boeing 787**	920km/h (Mach 0.85)

© WIKI Hansueli Krapf; Reaction Engines; DAVID ILIFF / NJR ZA; NASA; Illustration by Adrian Mann

FLY TO THE FUTURE

Teased by science fiction for decades, flying cars may finally be getting off the ground

DID YOU KNOW? *Eddie Rickenbacker wrote the first story about flying cars in July 1924*

When *The Jetsons* debuted on television in 1962, astronaut John Glen had just become the first American to orbit Earth. But during the optimism of the early space age, when rockets, satellites and nuclear power were on everyone's mind, it must have seemed like we would all be flying to work in a hover car like George Jetson within a few years. Yet despite ever more lifelike flying cars on screen — from Luke's landspeeder in *Star Wars* to those in the recent *Total Recall* remake — we're still waiting for them to make the leap from science fiction to science fact. However, that wait may soon be over.

This year has seen a flying car frenzy. At least two working prototypes have been unveiled, with the Lilium Jet going on its maiden voyage in Munich and the Kitty Hawk Flyer publicly demonstrated in San Francisco Bay. Meanwhile, ride-hailing app Uber has announced plans to launch a network of airborne taxis in Dubai and Texas, and Slovakian company Aeromobil is now reserving its fleet of 500 flying super cars to buy.

Google co-founder Larry Page has not only invested in Kitty Hawk this year but has also been funding another flying car company called Zee.Aero since 2010. Beyond the startup scene, both aerospace and auto industry giants, have also committed to developing honest-to-goodness flying cars.

So why now? The last few years have seen some major technological breakthroughs that could help flying cars finally lift off. Many of the designs we're seeing now use electric propulsion rather than jet fuel because battery technology has witnessed vast improvements driven by the demand for hybrid and electric cars.

While some concept vehicles still imagine humans in control behind the wheel, advances in so-called 'machine learning', which is essentially artificial intelligence, have led many companies to pursue self-driving flying cars. This means the user won't be required to own a pilot's licence, making flying cars more accessible for everyone.

For years little more than a fanciful sketch, flying cars are rapidly becoming a reality

EVOLUTION OF FLYING CARS

1917

Resembling a Model T with detachable triplane wings, the Curtiss Autoplane only achieved a few short hops and was grounded indefinitely once the US entered the First World War.

1921

The Tampier Roadable was a biplane with four wheels, removable wings and a land speed of 24 kilometres per hour. Its inventor Rene Tampier flew it to the Paris Air Salon then drove down the Champs-Élysées.

1946

The Airphibian was the first flying car to be certified as safe to fly by the US government and famed pilot Charles Lindbergh also endorsed it. But escalating development costs meant the inventor was forced to abandon it.

1957

The US Army developed the Piasecki VZ-8, a hybrid jeep-helicopter that could fly low enough to evade radar. It had two large horizontal propellers that allowed it to take off vertically and fly at 136 kilometres per hour.

1965

The Wagner Aerocar's bubble cockpit and tailfins make it look more like a helicopter with wheels than something out of *The Jetsons*. Its development was suspended in 1971.

1990s

The Moller M400 Skycar caused quite a buzz in the 90s with its sleek, rocket-like design. Sadly, Moller has since abandoned the project and is auctioning off the prototype through eBay.

1980s

Looking like something out of the kitsch 1970s version of *Battlestar Galactica* (in a good way), Boeing built three prototypes for its Sky Commuter, but the project was ultimately scrapped.

2017

Lilium completed a successful test flight of the world's first all-electric vertical take off and landing jet in 2017. The tested prototype was a two-seater, but the finished jet will carry five passengers.

> "AeroMobil is now reserving its fleet of 500 flying super cars to buy"

© WIKI; Ehang; Boeing; Lilium; Moller

The popularity of consumer drones, while much smaller and lighter, have also helped to drive down the cost of some components. In fact, the industries overlap; Chinese drone maker EHang are developing a self-flying taxi that looks like an oversized quadrocopter.

However, having been cruelly let down by pie in the sky fantasies about flying cars in the past, it's important that we stay grounded. Most of the manufacturers that have made announcements this year also say we won't actually be whizzing through the skies until 2020 or 2025. While the tech that underpins these vehicles is pretty much there, it will take years to fully develop them, carry out the necessary test flights and safety checks, as well as make the whole process simple enough that these flying cars could be affordably mass-produced.

Despite spurring on many of the innovations that make flying cars possible, Tesla CEO Elon Musk has reservations about flying cars. "Obviously, I like flying things," he told *Bloomberg*, referring to his other side line, private rocket company Space X. "But it's difficult to imagine the flying car becoming a scaleable solution." He also has concerns about mid-air fender benders. "If somebody doesn't maintain their flying car, it could drop a hubcap and guillotine you," Musk said. "Your anxiety level will not decrease as a result of things that weigh a lot buzzing around your head."

It's easy to dismiss Musk's skepticism due to the fact he is developing an entirely different form of transport that would see drivers travel in high-speed underground tunnels or 'hyperloops' rather than fly. However, many aerospace engineers and aviation experts have expressed similar concerns about the danger of the sky filling up with commuter traffic as airports, urban helipads and air traffic control would come under unprecedented pressure.

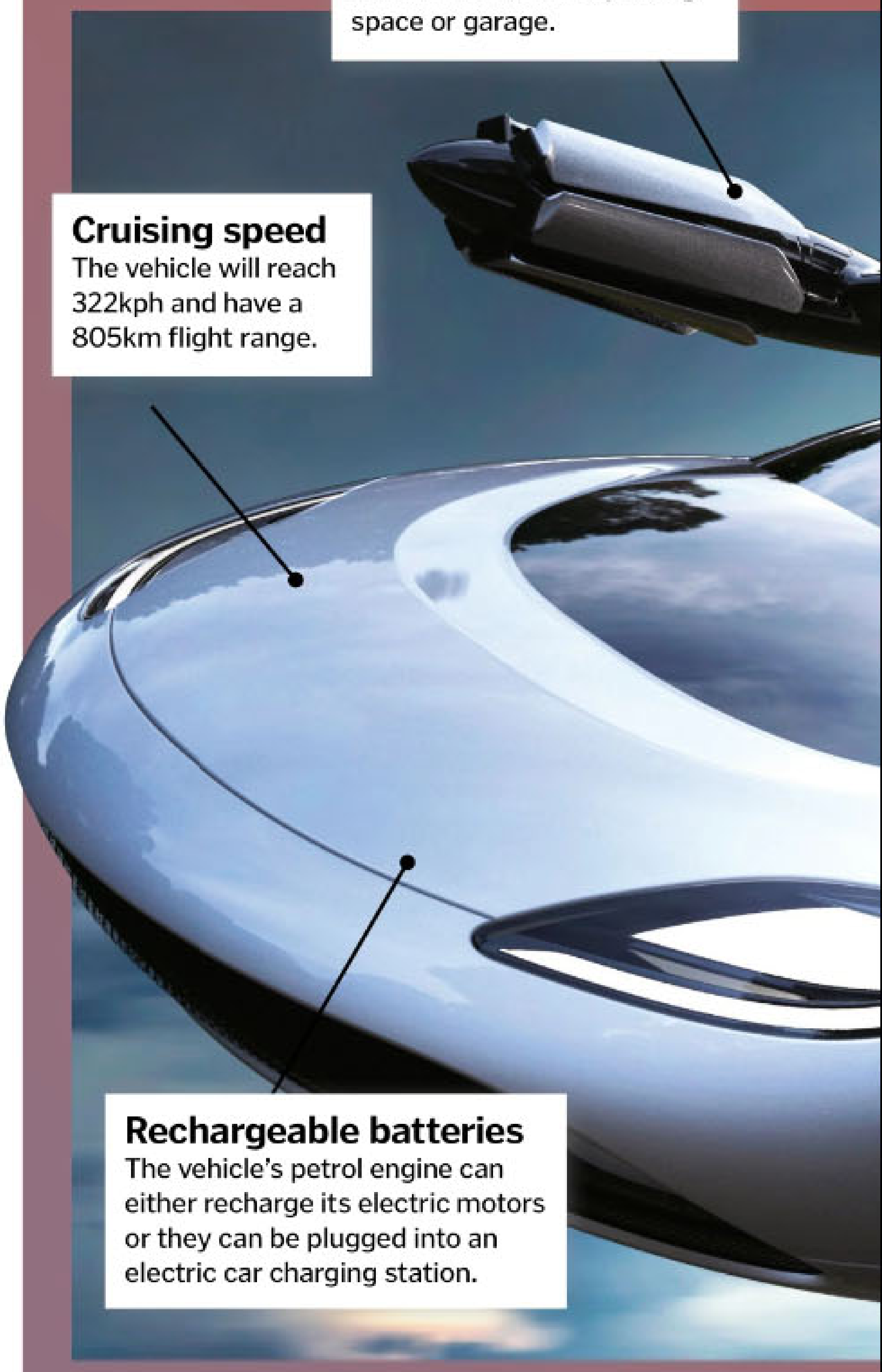
As part of their plans to create a fleet of flying taxis, Uber have committed to building so-called 'vertiports'. On the one hand these are intended to ensure that landing pads are as accessible to users as their conventional, earthbound taxis. However, they'll also go a long way to easing demand on existing infrastructure.

Chinese firm EHang plan to build private air traffic control towers wherever their passenger drones operate. One of these 'command centres' is already up and running in Guangzhou, where EHang carry out their test flights. These centres will monitor the autonomous shuttles, receiving live feed readings, including speed, altitude, individual propeller power, and location. The staff will be able to view camera feeds from the drone and communicate with passengers inside.

These are only the first steps towards making our skies safe for airborne commuters; government agencies in every country will likely impose their own rules and restrictions. However, if rules for the sky can be established, flying cars have the power to transform not just the way we travel but how we live our lives.

Alternatively, if we all get used to living the high life, jetting from location to location, is there even any reason to return to street level? Read on to discover how flying cars have evolved, the tech that makes them tick and what the future may look like when they finally fulfil our Jetson dreams.

The Aeromobil's chassis is made almost entirely out of ultra lightweight carbon fibre



Simple storage
The TF-X's wings fold up so compactly the vehicle can be stored in a standard parking space or garage.

Cruising speed
The vehicle will reach 322kph and have a 805km flight range.

Rechargeable batteries
The vehicle's petrol engine can either recharge its electric motors or they can be plugged into an electric car charging station.

FLIGHT OF FANCY? THE CHALLENGES FACING FLYING CARS

Regulation

Even if flying cars overcome all technical barriers, regulation — from safety standards to air traffic control — will be a major hurdle and likely take years for lawmakers to agree on. Self-flying cars will probably have to meet additional standards.

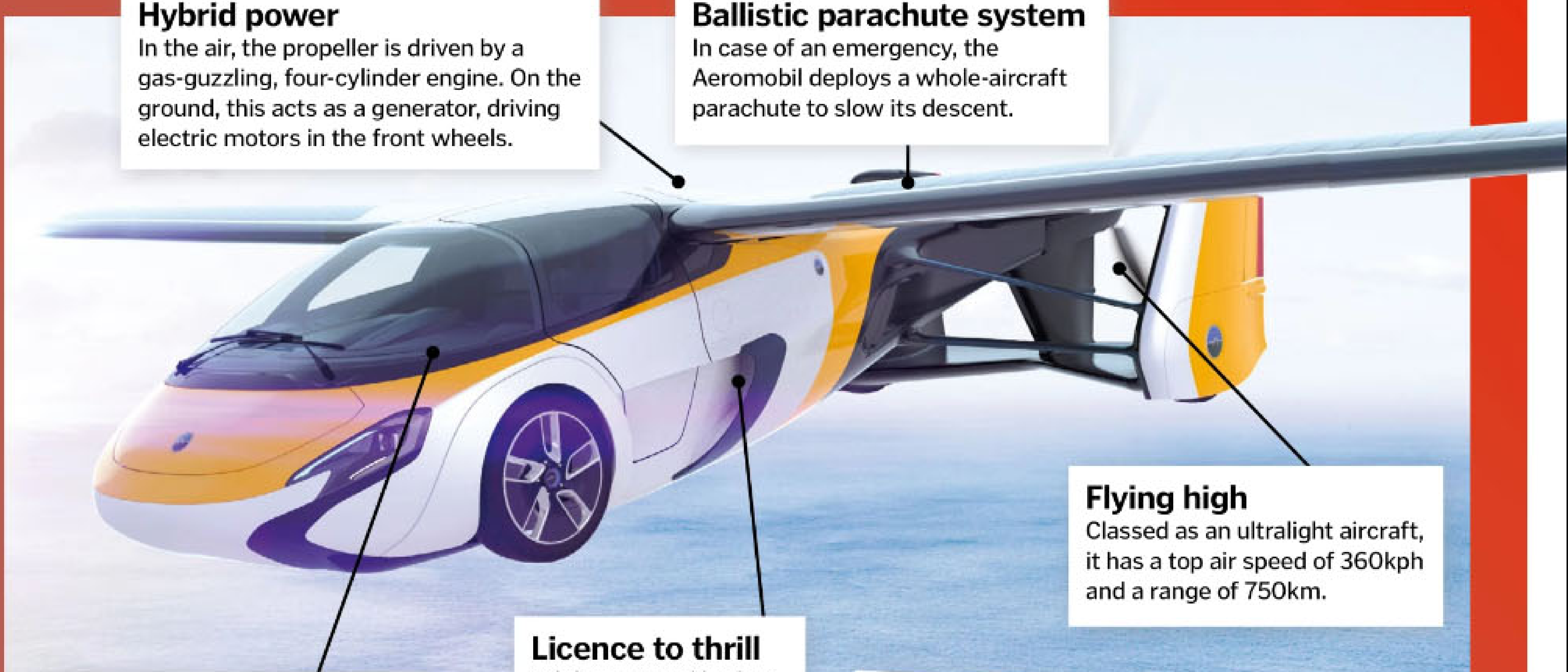
Fuel consumption

It takes a lot of power to defy gravity, which can be expensive and polluting. Advances in battery tech might offer an alternative, but jet fuel still packs more energy per kilogram, a key consideration in an industry where weight trumps just about everything.

DID YOU KNOW? The Aeromobil steering wheel has a large red button marked "Launch" that you press to make the car transform

The flying car in disguise

The Aeromobil is a real-life Transformer. To see it in driving mode you could mistake the slick carbon fibre Aeromobil for some kind of experimental supercar. But in just three minutes this sporty two-seater can be ready for take off as wings unfurl from its roof and a rear propeller pops out at the back. Then all you need is an airfield or a long stretch of empty road and you're cruising at 10,000 feet. Unfortunately, the Aeromobil is also being sold like a supercar — only 500 are being made and each one will cost $1.2 million (£908,400).



Hybrid power
In the air, the propeller is driven by a gas-guzzling, four-cylinder engine. On the ground, this acts as a generator, driving electric motors in the front wheels.

Ballistic parachute system
In case of an emergency, the Aeromobil deploys a whole-aircraft parachute to slow its descent.

Flying high
Classed as an ultralight aircraft, it has a top air speed of 360kph and a range of 750km.

Digital cockpit
The driving seat is surrounded with digital displays showing necessary information for both driving and flight modes.

Licence to thrill
While you need both a driving and pilot's licence to operate the Aeromobil, the aim is for future versions to be fully autonomous.

Easy rider
The vehicle will be certified as a Light Sport Aircraft in the US so that it can be flown with a pilot's licence that only requires 20 hours training.

Vertical take off
The TF-X's propellers will shift from a vertical to a horizontal position and be powered by a 300-horsepower engine.

The TF-X is (almost) ready for vertical take off

Terrafugia (Latin for 'escape the Earth') has been developing flying cars since 2006. Its most exciting concept, the TF-X, looks like a four-seater SUV with fold-up wings. But its most exciting feature is that its propellers can shift position so that the TF-X can vertically take off and land (VTOL) like a helicopter — meaning it doesn't require a long runaway — before switching to conventional horizontal flight. Terrafugia has been teasing flying car tech for years now, but its recent purchase of Volvo's parent company Geely might get the TF-X off the ground.

> "Many engineers have expressed concerns about the sky filling with traffic"

Noise pollution
As anyone who has heard a helicopter land or flown a drone will know, VTOL vehicles, which generate a lot of downward force, make a lot of noise for people on the ground. This will not endear flying cars to the public.

Qualified pilots
Even if the controls can be simplified (perhaps with the aid of AI), flying a vehicle requires a different set of skills to driving. Alternatively, hiring a pilot to fly you can cost £500 ($660) an hour.

Infrastructure
Most major cities boast a few helipads, but these are not designed to handle heavy commuter traffic. Uber plans to build its own urban vertiports to ease the burden, but these will have to meet strict regulations and will possibly face opposition from local residents.

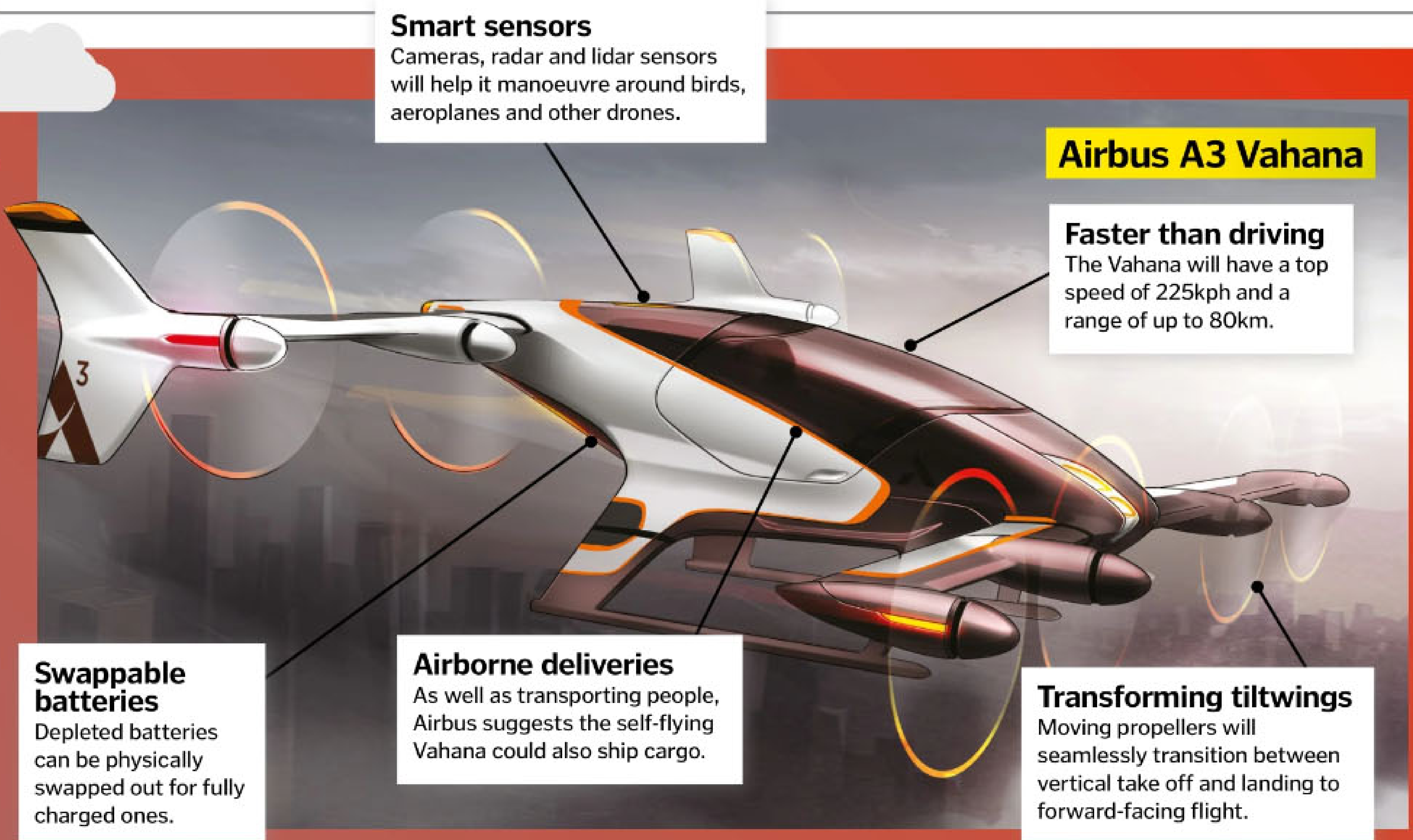
© Getty; Aeromobil

SKY RIDE

These airborne options plan to offer customers low-cost, short-distance rides

A realistic flying machine

While there are lots of startups promising they will invent the flying car first, Airbus is approaching the challenge with nearly 50 years experience building real-life planes. While it looks like something out of science fiction, the Airbus A3 Vahana (pronounced 'A-cubed') is designed around existing wing and landing gear technology. A full-sized prototype is already in the works, with demonstrations promised before the end of 2017.



Airbus A3 Vahana

Smart sensors
Cameras, radar and lidar sensors will help it manoeuvre around birds, aeroplanes and other drones.

Faster than driving
The Vahana will have a top speed of 225kph and a range of up to 80km.

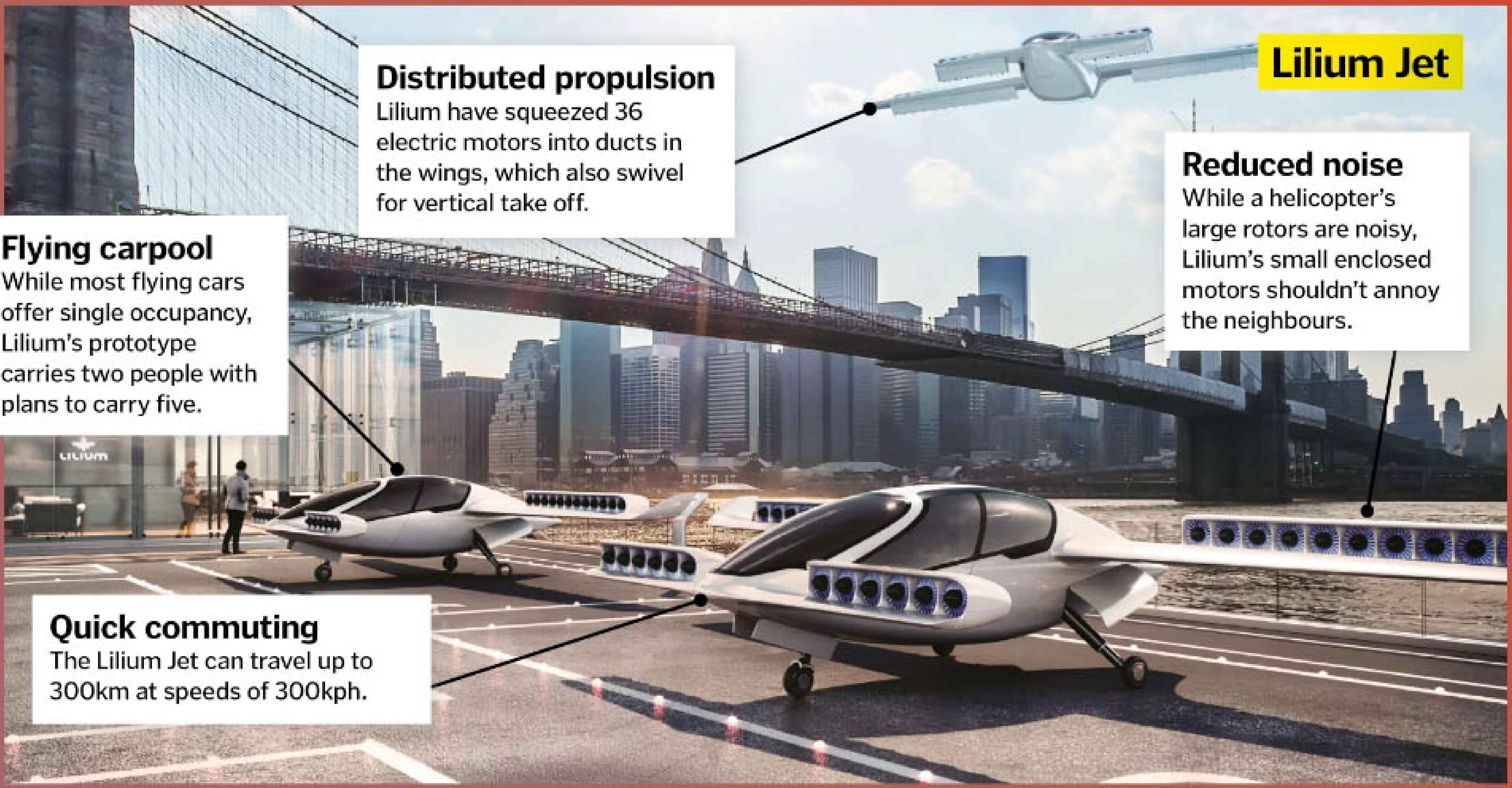
Swappable batteries
Depleted batteries can be physically swapped out for fully charged ones.

Airborne deliveries
As well as transporting people, Airbus suggests the self-flying Vahana could also ship cargo.

Transforming tiltwings
Moving propellers will seamlessly transition between vertical take off and landing to forward-facing flight.

The Lilium Jet doesn't actually use jet fuel

In April, the Lilium Jet made its maiden voyage at a Munich airfield, proving that this all-electric aircraft can take to the sky. However, its flight only lasted a few minutes, with no one in either of its two seats and a pilot controlling it from the ground. Backed by the European Space Agency, Lilium is confident it can develop the battery power needed to offer an on-demand taxi service by 2025.



Lilium Jet

Distributed propulsion
Lilium have squeezed 36 electric motors into ducts in the wings, which also swivel for vertical take off.

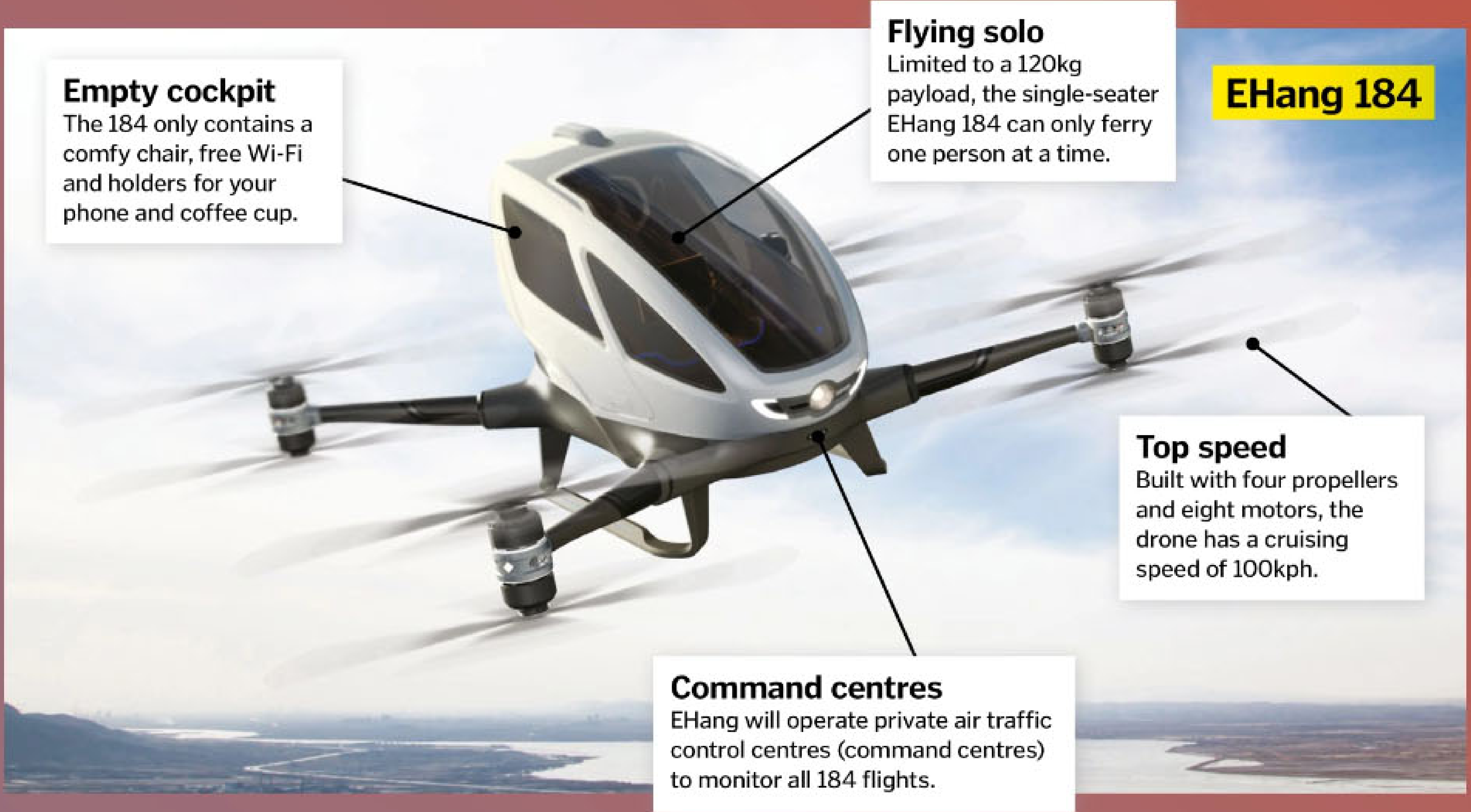
Reduced noise
While a helicopter's large rotors are noisy, Lilium's small enclosed motors shouldn't annoy the neighbours.

Flying carpool
While most flying cars offer single occupancy, Lilium's prototype carries two people with plans to carry five.

Quick commuting
The Lilium Jet can travel up to 300km at speeds of 300kph.

The self-piloting drone that you can ride inside

The 1.4-metre-high EHang 184 can fly passengers distances of up to 16 kilometres at around 100 kilometres per hour. The 184 flies itself, so all you have to do is punch your destination into a smartphone app that connects with the 184 via the vehicle's built-in Wi-Fi and off you go. Though a summer trial had to be rescheduled, EHang are expected to buzz passengers around Dubai soon.



EHang 184

Flying solo
Limited to a 120kg payload, the single-seater EHang 184 can only ferry one person at a time.

Empty cockpit
The 184 only contains a comfy chair, free Wi-Fi and holders for your phone and coffee cup.

Top speed
Built with four propellers and eight motors, the drone has a cruising speed of 100kph.

Command centres
EHang will operate private air traffic control centres (command centres) to monitor all 184 flights.

DID YOU KNOW? While privately owning a flying car will be pricey, Airbus estimate a taxi ride will only cost $1.50 to $2.50 per mile

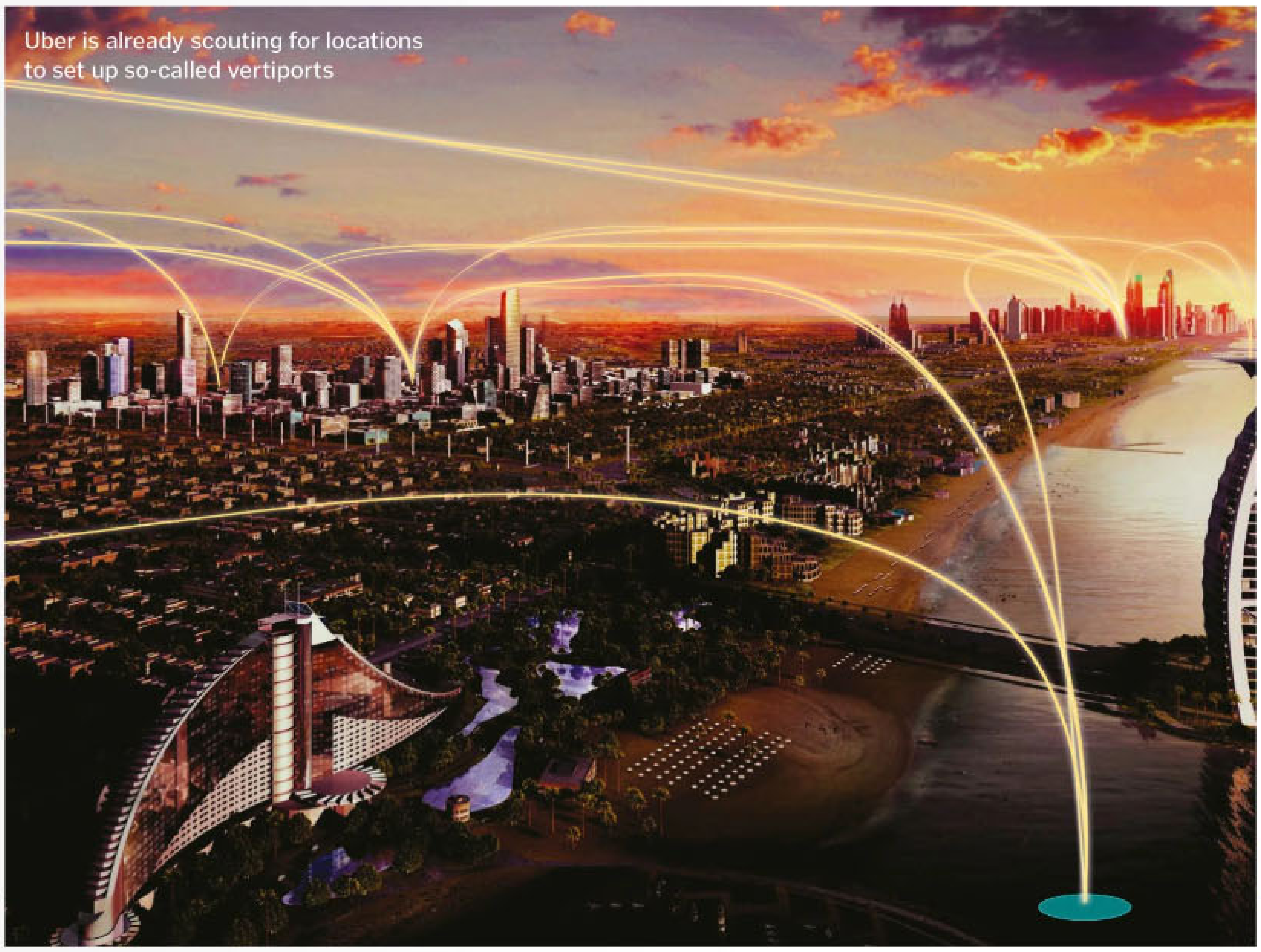
Up, up and Uber!

Ride-hailing service Uber has announced it is also taking to the skies. The company will trial UberAIR flying taxis in Dubai and Dallas in 2020, which passengers will be able to summon using its regular mobile app.

"Urban aviation is a natural next step for Uber in this pursuit, which is why we are working to make 'push a button, get a flight' a reality," said Uber's chief product officer Jeff Holden at a press event. Holden added that while these flights will initially involve manned aircraft, they will eventually be cheaper, faster and more environmentally friendly than conventional Uber rides as they will use autonomous electric aircraft.

Uber has hired Mark Moore, a NASA aircraft engineer renowned for his VTOL work, and partnered with several aeronautic manufacturers to develop these vehicles. Once operational, Uber also plans to build vertiports — landing pads with charging ports — in easily accessible urban areas.

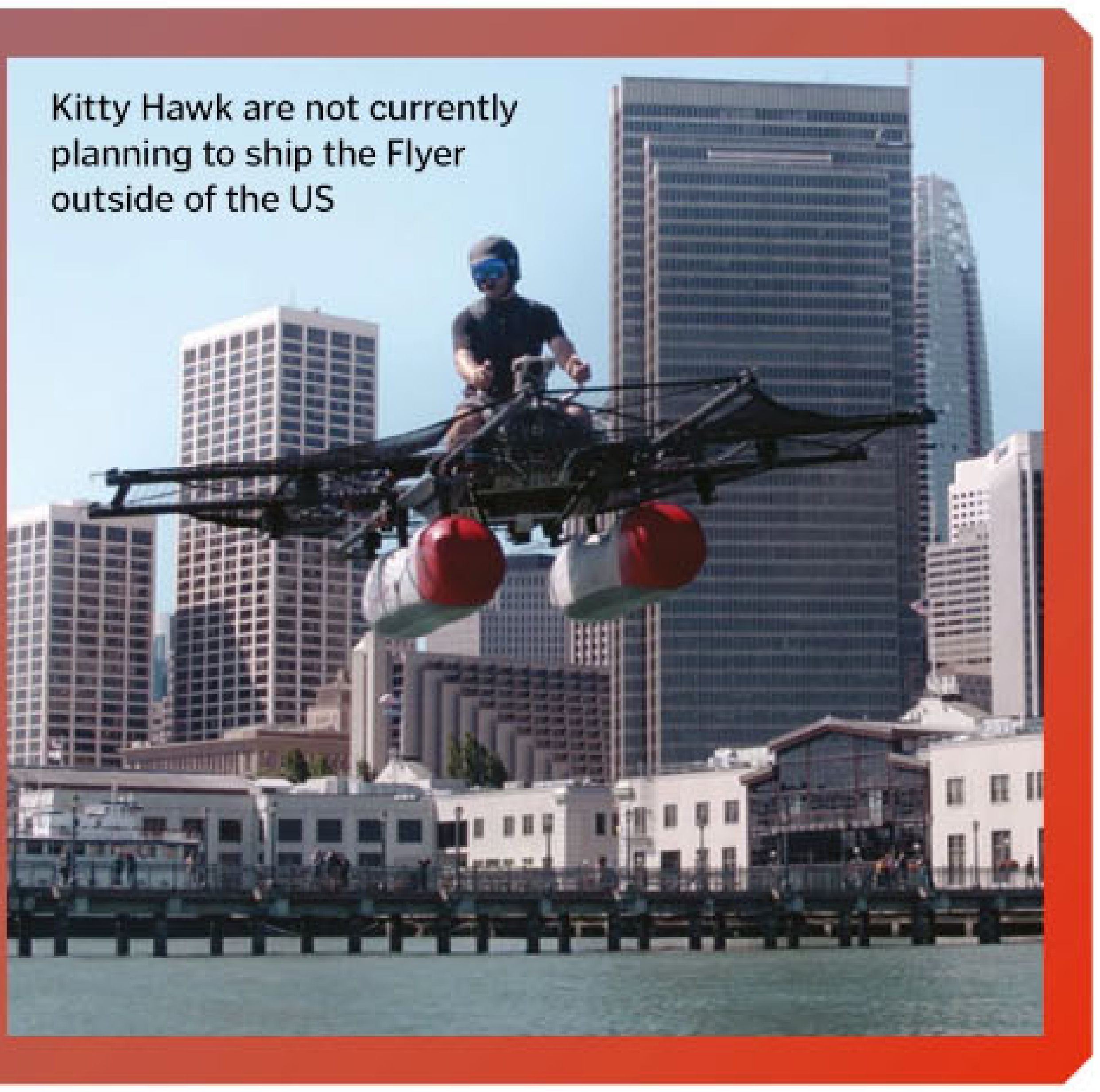
UberAIR will operate a network of aircraft flying distances of up to 40 kilometres



Uber is already scouting for locations to set up so-called vertiports

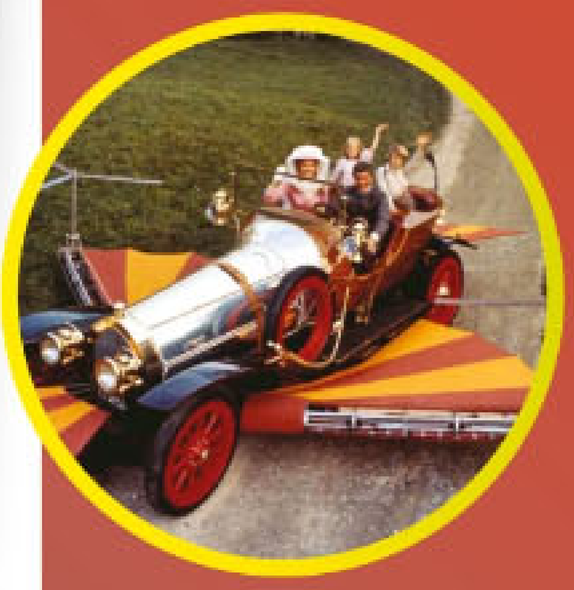
Kitty Hawk set to make a splash

Less of a flying car and more of a hovering jet ski, the Kitty Hawk Flyer is a single-person ultralight aircraft powered by eight electric rotors. Backed by Google co-founder Larry Page, the Flyer travels up to 40 kilometres an hour and lifts up to 4.5 metres into the air. Like the jet ski, the Flyer is recreational rather than a main mode of transport, designed strictly for use over water. However, Kitty Hawk insist that it doesn't require a pilot's licence to fly and you can master the controls within hours. A price has yet to be confirmed, but Kitty Hawk plan to start selling the Flyer (with more aesthetically pleasing bodywork) by the end of the year.



Kitty Hawk are not currently planning to ship the Flyer outside of the US

TOP 5 FICTIONAL FLYING CARS



Chitty Chitty Bang Bang, *Chitty Chitty Bang Bang* (1968)

Created by eccentric inventor Caractacus Potts, the family-sized Chitty Chitty Bang Bang can fly the length of Europe and has a floatation device for evading pirates on water.

Scaramanga's AMC Matador, *The Man With The Golden Gun* (1974)

Bond villain Scaramanga used a Coupé that transformed into a plane for a daring kidnap. 007 mentions it flying "200 miles west of Bangkok".

Police Spinner, *Blade Runner* (1982)

Ideal for patrolling the skyscrapers that loom over futuristic LA, the police cars in Ridley Scott's sci-fi detective story take off vertically and hover in the air like a Harrier Jump Jet.

DeLorean DMC-12, *Back To The Future Part II* (1989)

As if turning it into a time machine in the first film wasn't enough, Doc Brown upgrades his car for the sequel with technology from 2015, where all cars — and skateboards — fly.

Skyjet, *Valerian and the City of a Thousand Planets* (2017)

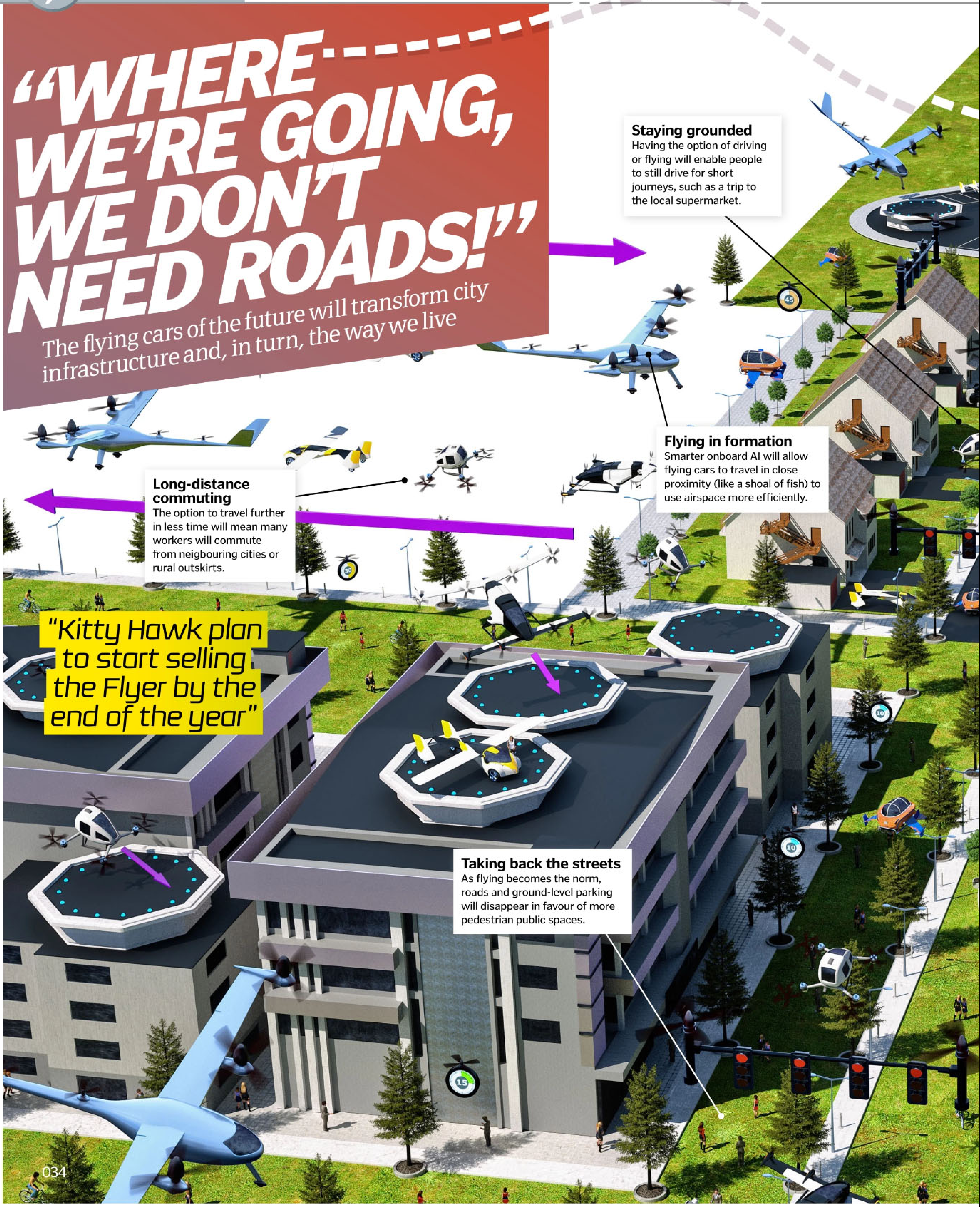
The Skyjet in Luc Besson's sci-fi epic can switch between urban and interstellar travel and was designed by real-life manufacturer Lexus.

> "Uber is set to trial flying taxis in Dubai and Dallas in 2020"

© Lilium; Airbus; E-Hang; Kitty Hawk, Photographer: Ian Martin; Uber; Getty/Warner Bros/ Handout; Alamy

"WHERE WE'RE GOING, WE DON'T NEED ROADS!"

The flying cars of the future will transform city infrastructure and, in turn, the way we live



Staying grounded
Having the option of driving or flying will enable people to still drive for short journeys, such as a trip to the local supermarket.

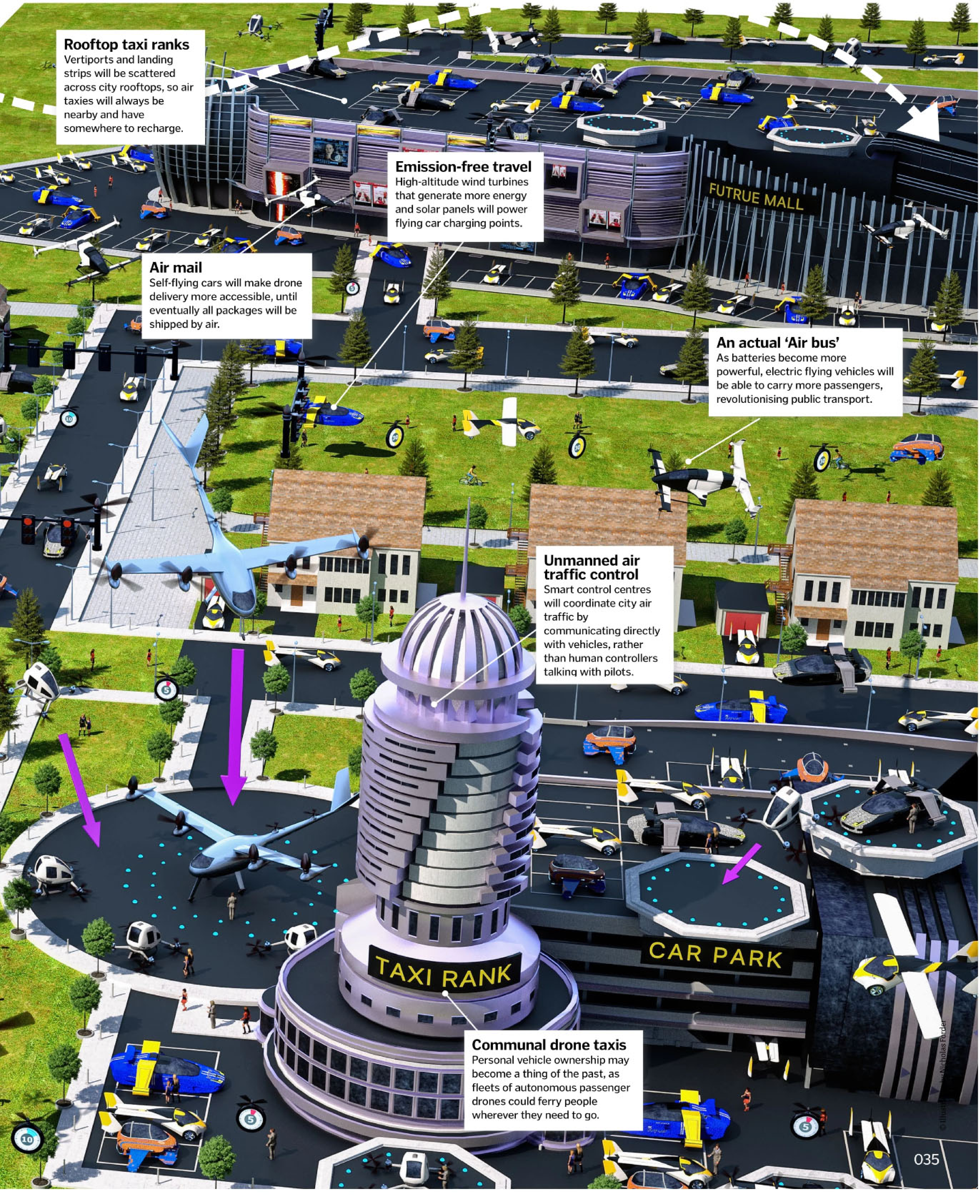
Long-distance commuting
The option to travel further in less time will mean many workers will commute from neigbouring cities or rural outskirts.

Flying in formation
Smarter onboard AI will allow flying cars to travel in close proximity (like a shoal of fish) to use airspace more efficiently.

> "Kitty Hawk plan to start selling the Flyer by the end of the year"

Taking back the streets
As flying becomes the norm, roads and ground-level parking will disappear in favour of more pedestrian public spaces.

DID YOU KNOW? *A robot arm made by Tesla can swap out rechargeable batteries in 90 seconds and could be used on flying cars*



Rooftop taxi ranks
Vertiports and landing strips will be scattered across city rooftops, so air taxies will always be nearby and have somewhere to recharge.

Emission-free travel
High-altitude wind turbines that generate more energy and solar panels will power flying car charging points.

Air mail
Self-flying cars will make drone delivery more accessible, until eventually all packages will be shipped by air.

An actual 'Air bus'
As batteries become more powerful, electric flying vehicles will be able to carry more passengers, revolutionising public transport.

Unmanned air traffic control
Smart control centres will coordinate city air traffic by communicating directly with vehicles, rather than human controllers talking with pilots.

Communal drone taxis
Personal vehicle ownership may become a thing of the past, as fleets of autonomous passenger drones could ferry people wherever they need to go.

© Illust[illegible] Nicholas Forder

On board the Dream Chaser

With the Space Shuttle in retirement, NASA is looking to the next generation of space planes

Sierra Nevada's Dream Chaser is a smaller, more adaptable version of the Space Shuttle and will spend much of its time going on trips to resupply the International Space Station (ISS). Unlike the Space Shuttle, Dream Chaser can fly autonomously, without a human pilot. Crewed versions will also be developed, capable of carrying seven astronauts plus cargo.

Once in space, it will be powered by twin hybrid rocket engines, which use two propellants – one solid, the other gaseous or liquid. These are mixed together and tend to be less explosive than purely solid rocket fuel when they fail. In the case of Dream Chaser, the solid propellant is a rubbery material called 'hydroxyl-terminated polybutadiene', while the gas propellant is nitrous oxide. Its engines are so powerful that, when docked with the ISS, Dream Chaser can raise the Space Station's altitude, useful for avoiding pieces of space debris.

Dream Chaser is a fairly modest spacecraft in terms of size; its wingspan is seven metres, compared to the 23.8-metre wingspan of the Space Shuttle. It will be capable of carrying over five tons of cargo into space before returning to Earth hours later, landing like an airplane on a runway.

Expected to first launch sometime in 2018-2019, there will be two versions; the Dream Chaser Cargo System sports folding wings to allow it to fit into the cargo fairing rockets such as the Ariane 5, while the crewed Dream Chaser Space System will launch on an Atlas V rocket to carry astronauts to the ISS.

The Dream Chaser will be able to return from space and land like an airplane

Compared to the giant Space Shuttles, Dream Chaser is modest in size

Spacecraft design

Mark Sirangelo, head of Sierra Nevada Corporation Space Systems, tells us more

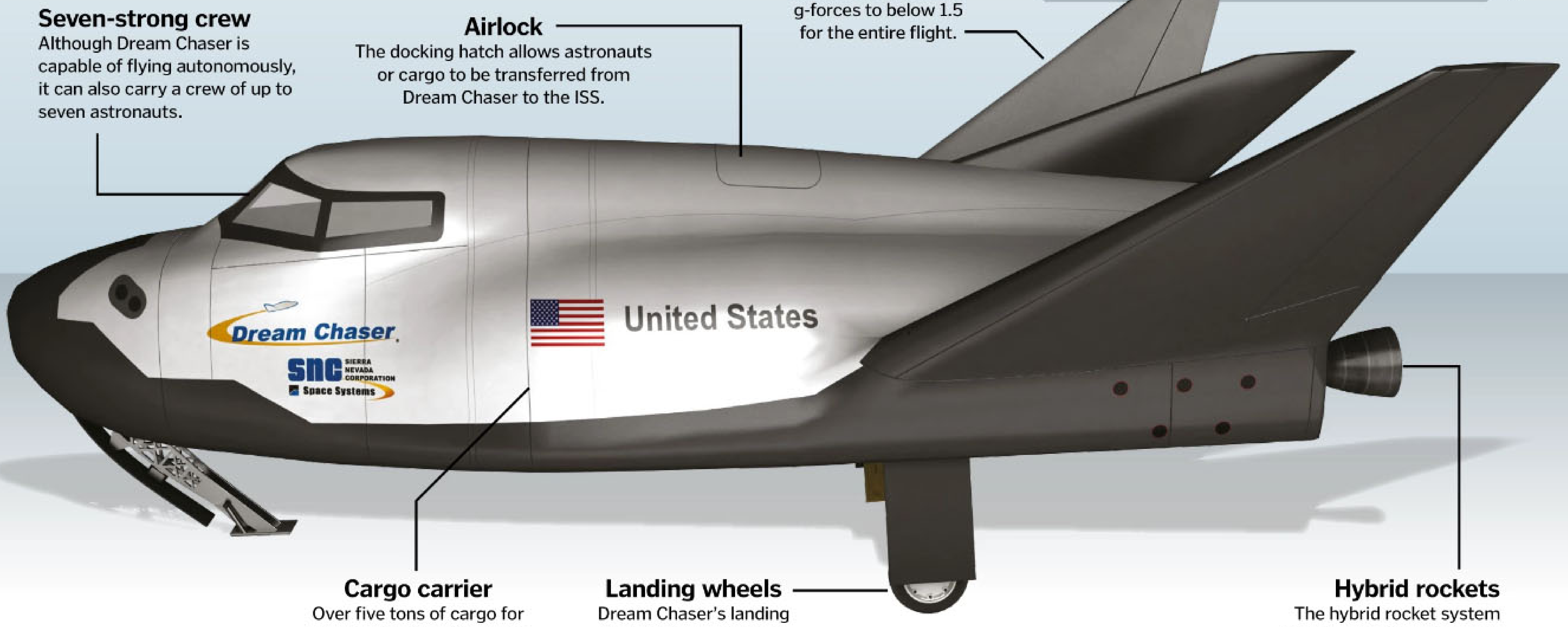
"Dream Chaser is a pilot-automated space plane that has many similarities to the Space Shuttle. It is smaller in terms of overall size – it doesn't have the huge cargo compartment that the Shuttle did – but it has a similar sized pressurised crew compartment. This means that it can still take up the same number of astronauts (seven) and the same amount of protected cargo in the pressure hold as the Shuttle.

It's a highly reusable vehicle and, presuming that there's a mission and rocket, we can launch each Dream Chaser vehicle potentially five times a year. We're planning on having a fleet so that we can fly one while we're getting the next one ready to fly again. We are expecting our first orbital flight to be in 2018 but we're probably not going to have any crew on board to begin with."

© Sierra Nevada Corporation

What dreams are made of

Introducing one of the most sophisticated space vehicles ever built



Seven-strong crew
Although Dream Chaser is capable of flying autonomously, it can also carry a crew of up to seven astronauts.

Airlock
The docking hatch allows astronauts or cargo to be transferred from Dream Chaser to the ISS.

Wing profile
Dream Chaser's streamlined shape with upswept wings keeps g-forces to below 1.5 for the entire flight.

Cargo carrier
Over five tons of cargo for resupplying the ISS can be crammed into Dream Chaser's hold.

Landing wheels
Dream Chaser's landing gear allows it to touch down on a runway just like an airplane.

Hybrid rockets
The hybrid rocket system uses non-toxic propellants for the first time in the history of space flight.

DID YOU KNOW? *Simple hand gestures can be used to activate the Motorrad VISION NEXT 100's indicator lights while riding*

The rise of smart motorcycles

BMW has unveiled a high-tech bike concept that is impossible to topple over

If the rider looks down while wearing the visor, a map of their route will appear

Predicting a future where most vehicles will be driverless, BMW hopes to still provide bikers with a thrilling, hands-on ride. To celebrate its centenary year, the company has unveiled the Motorrad VISION NEXT 100 concept, a high-tech bike designed for the digitally connected world of the future.

While it may look a bit like something from *Tron*, the motorcycle does in fact take inspiration from a classic, as the black triangle frame is a subtle reference to the R32, BMW's first ever motorcycle, released in 1923. However, this new upgrade has some rather more sophisticated features on board, including self-balancing technology. If the bike is about to tip over it will automatically right itself, even when stationary, meaning the rider won't fall off and can dismount without the need to flick out a stand.

Thanks to this safety feature, BMW doesn't foresee a need for riders to wear a helmet, instead equipping them with a special visor that acts as a digital companion. If they look straight ahead, symbols suggesting their ideal banking angle and warning of any upcoming hazards will appear in their field of view, while if they look up, a rear-view function will activate, allowing them to see what's going on behind. The accompanying suit is also designed to enhance the riding experience, with a neck section that inflates for support when accelerating.

The BMW Motorrad VISION NEXT 100

The bike BMW thinks you'll be riding three decades from now

1. Flexible frame

With no bearings or joints, the entire frame adjusts with a turn of the handlebars, changing the direction of the bike.

2. Zero emissions

Designed to look like a traditional BMW boxer engine, the fully electric power unit extends outwards when the bike is in motion.

3. Visor display

As well as providing wind protection, the visor also features an information display, which can be controlled by the rider's eye movements.

4. Comfortable suit

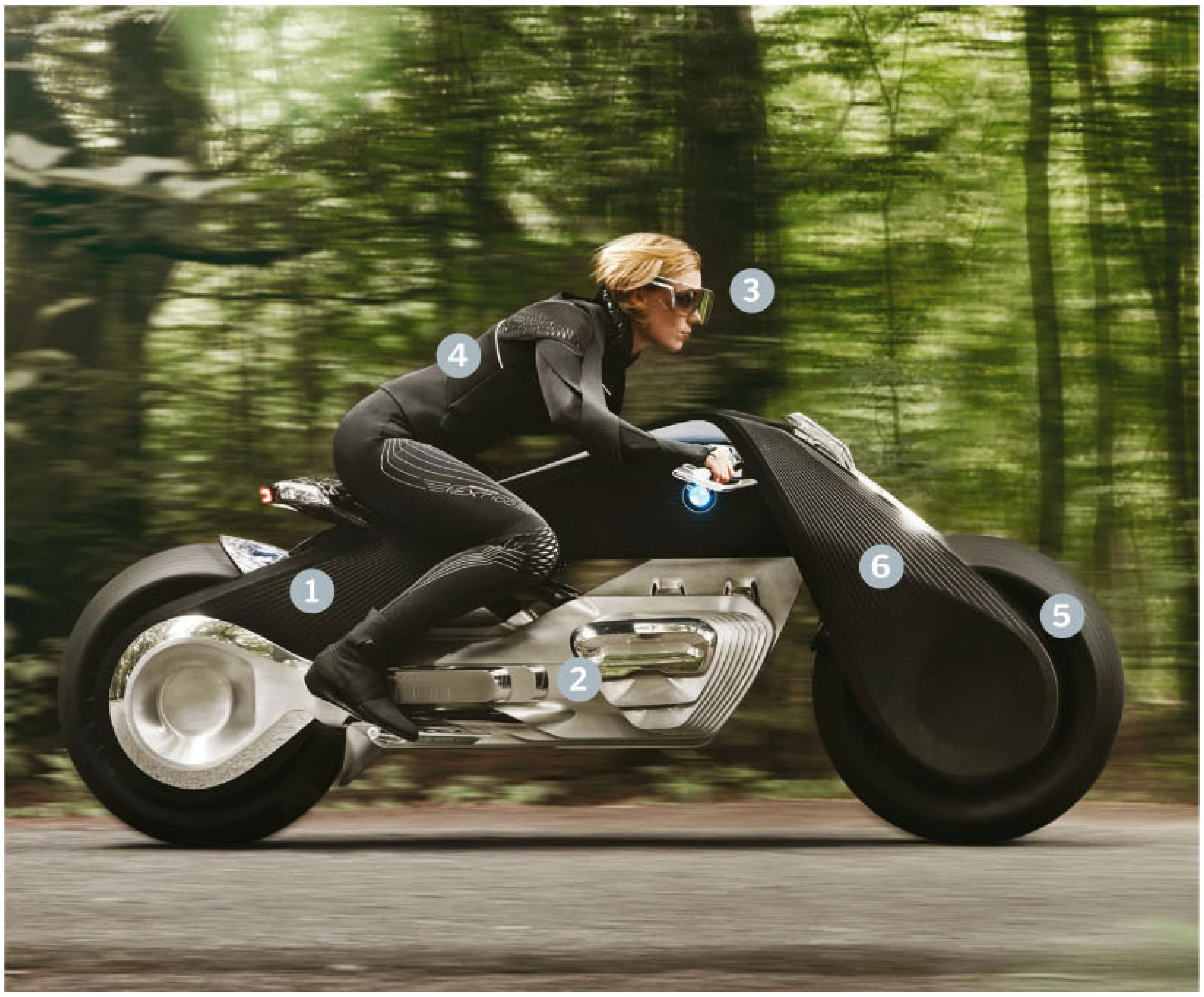
The suit monitors the rider's body temperature, adjusting the level of heat accordingly, and vibrates to give navigation instructions.

5. Adaptive tyres

The variable tread of the tyres automatically adjusts to grip onto any road surface, whatever the conditions.

6. Modern materials

Under its matte-black fabric cover, the frame is made from carbon fibre, and so are the seat and wings.

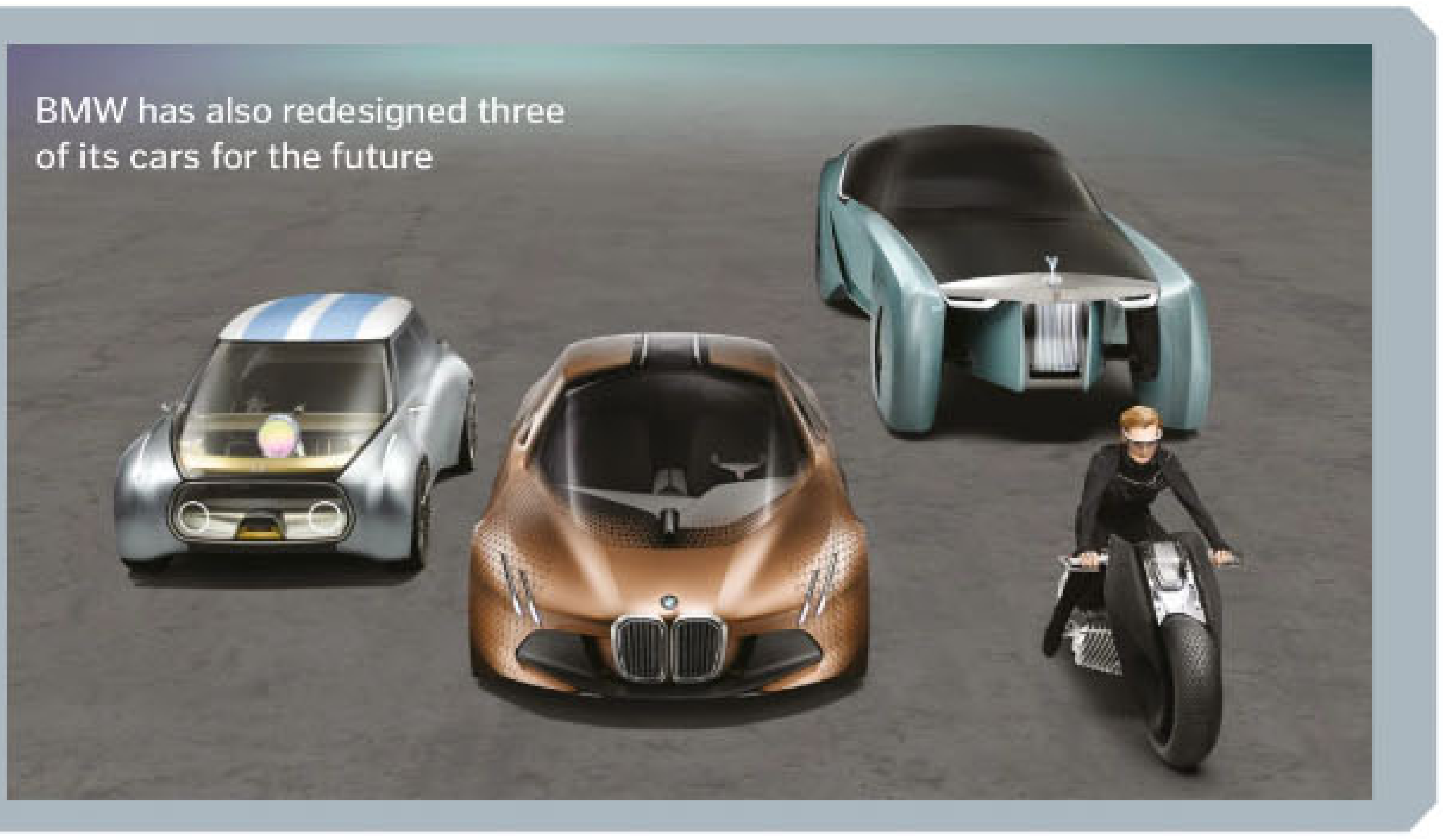


More future vehicle concepts

The motorcycle isn't the only vehicle BMW has re-imagined for the future. As part of its VISION NEXT 100 exhibition, the company has also designed concepts for three of its car brands: MINI, Rolls Royce and BMW. The idea for the MINI is to have a network of cars available at all times, able to autonomously pick up drivers who can then adjust the car's appearance, driving characteristics and connectivity to suit their preferences.

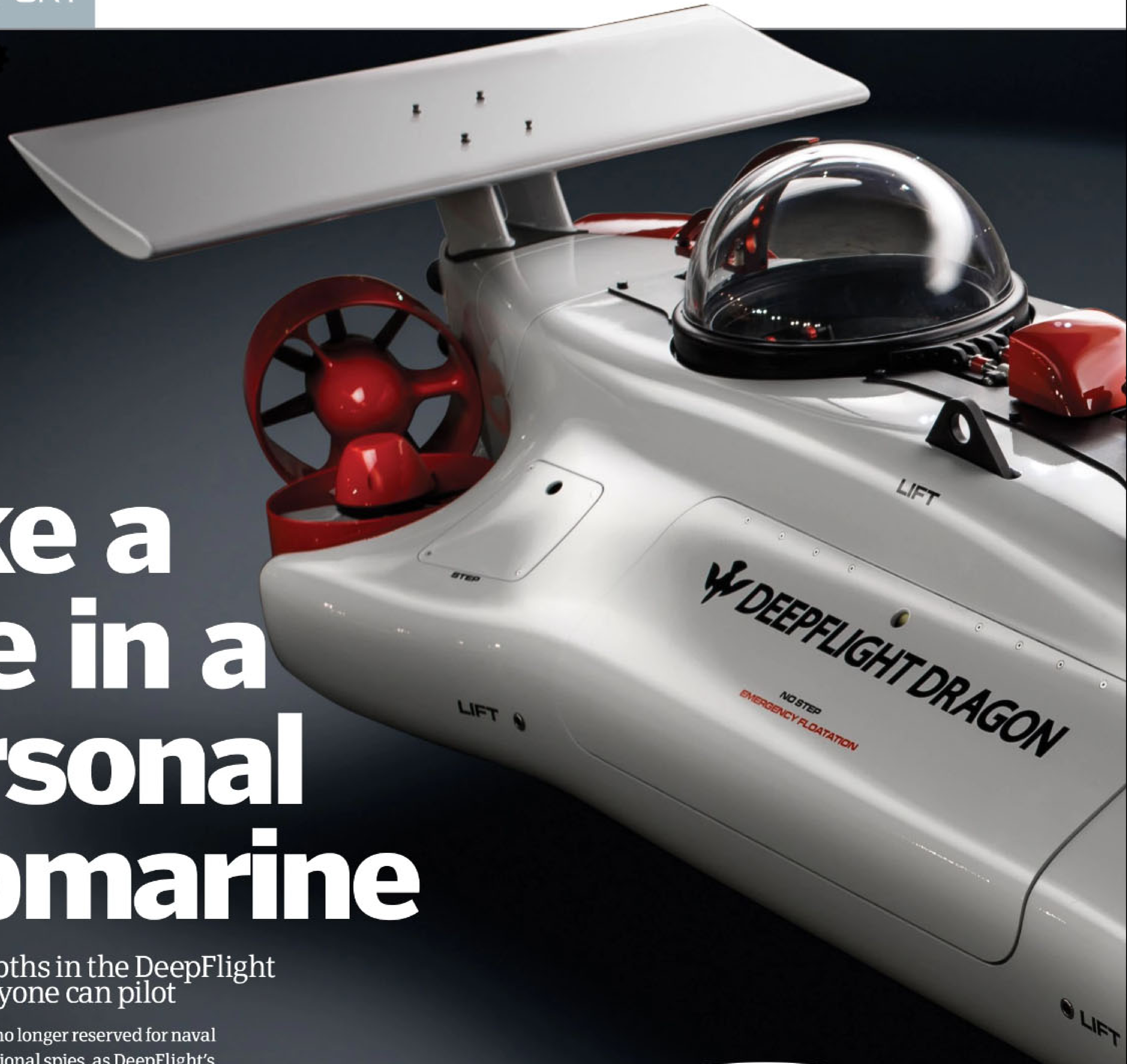
The Rolls Royce, on the other hand, won't need a driver at all, as it will be controlled by a virtual personal assistant who can also fulfil your every wish throughout the journey. Customers will be able to create their own customised version of the car, which will be spacious enough for them to stand up inside.

The BMW combines the best of both worlds, allowing the driver to take the wheel themselves or hand over control if they want to sit back and relax.



BMW has also redesigned three of its cars for the future

© BMW Group



Take a ride in a personal submarine

Explore the depths in the DeepFlight Dragon that anyone can pilot

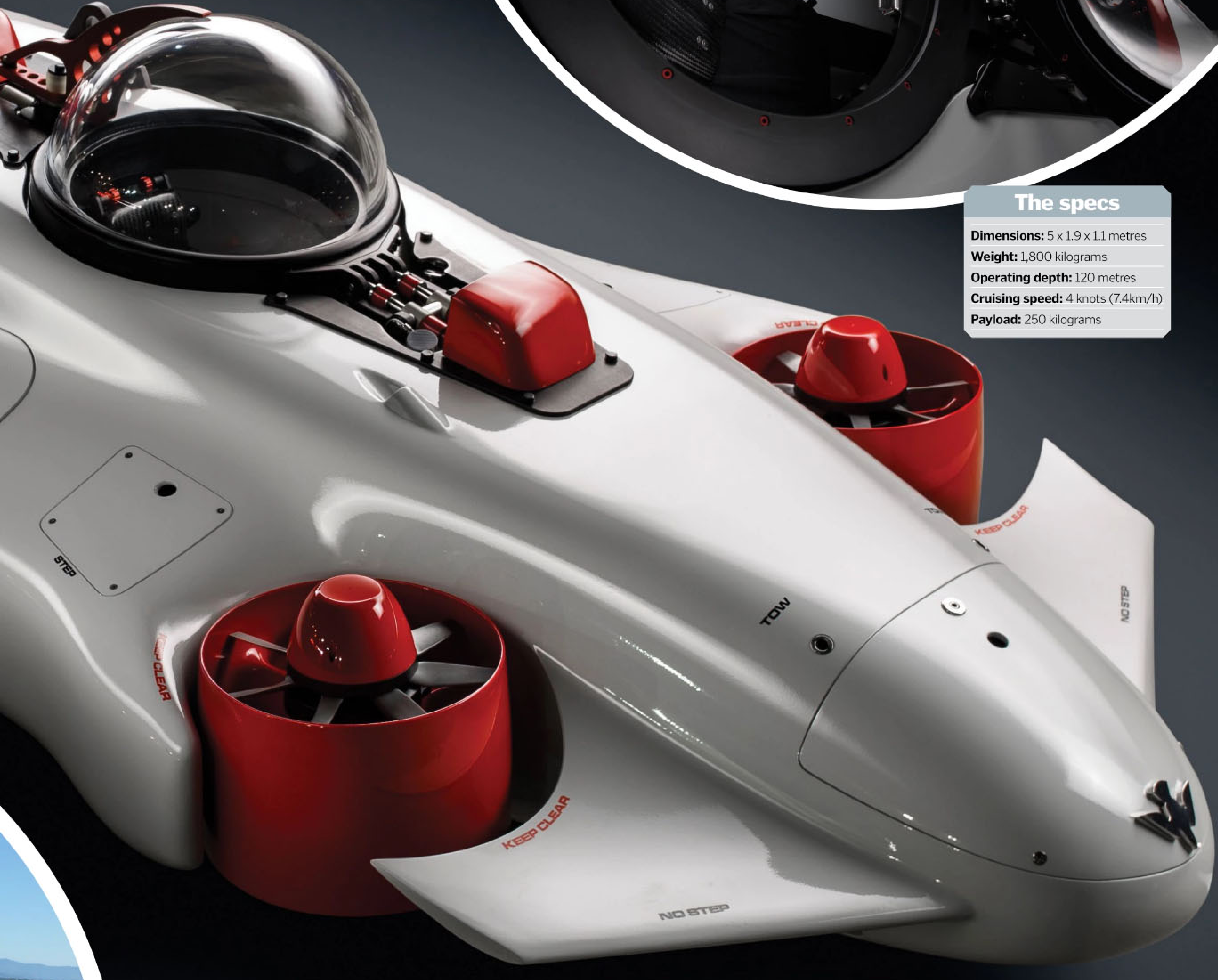
Submarines are no longer reserved for naval warfare and fictional spies, as DeepFlight's new craft has made it easy for anyone to travel beneath the waves. The Dragon is a cross between a submarine and quadcopter, with six rotating thrusters that allow it to fly and hover underwater. The simple controls mean it operates just like a drone too, so anyone can pilot it without needing lengthy training.

The onboard DeepFlight Dive Manager monitors depth control, battery consumption and oxygen flow, so all you need to do is set the dive limit and fly. The lithium-iron-phosphate battery allows you to cruise for up to six hours between charges and operates quietly so you can sneak up on any marine wildlife. You and your passenger will be protected by the carbon composite chassis and pressurised cabin, and if you get into trouble, the sub's positive buoyancy will cause it to automatically float back to the surface.

You don't need much know-how to own a Dragon, but you do need deep pockets. The craft is available for an eye-watering £1 million ($1.5 million), but the good news is that it will fit perfectly on your yacht.

The two-seater sub can be controlled by either the front or back passenger

Simple controls make the Dragon very easy to operate with hardly any training



The specs

Dimensions: 5 x 1.9 x 1.1 metres
Weight: 1,800 kilograms
Operating depth: 120 metres
Cruising speed: 4 knots (7.4km/h)
Payload: 250 kilograms

The Dragon is the smallest and lightest personal submarine on the market

NEXT-GEN EMERGENCY VEHICLES

We reveal the latest tech to help pursue lawbreakers, extinguish infernos and save lives

Maintaining law and order can be a tough test so having top-notch technology to back you up is essential. Both the current and upcoming generation of emergency vehicles contain state-of-the-art kit that performs a variety of functions, whether aiding in the pursuit of criminals, dampening flames or preserving life.

From unmanned drones, to futuristic ambulances and high performance police Interceptors, the technology at the disposal of the emergency services is extremely sophisticated. Take the Oshkosh Striker fire engine, for example, which can pierce up to 142 centimetres (56 inches) of metal in order to access blazing infernos. Ambulances are also being revamped with the aim to kit out the vehicles with tools and apparatus that will be on par with the best a hospital can provide. Saving lives on the scene of an incident could become the norm in the near future.

Vehicles such as the Striker put efficiency and quality above everything else, while in Dubai police supercars are seen as the way forward. In the United Arab Emirates' largest city, everything is larger than life, and the police Lambos and Ferraris you see roaming the streets are no different.

Today's emergency services are also embracing less typical ways of maintaining order than before. Unmanned aerial vehicles (UAVs) are already making an impact in the world of policing, allowing for new and effective ways of tracking offenders from the skies. The Stealth motorcycle is another vehicle that moves away from the traditional methods of policing by accessing both crowded areas and off-road locations with ease.

All of the emergency departments are finding ways to make the daily routine safer, simpler and more efficient. To see just how these new vehicles will revolutionise public safety, **How It Works** is getting under the bonnet of the emerging cars, trucks and bikes available to the emergency services. The future is now.

DID YOU KNOW? *The ambulance size and design we see today only began in the 1970s. Before, ambulances were repurposed cars*

Inside an ambulance

How the ambulances of the world are the safest and best equipped they've ever been

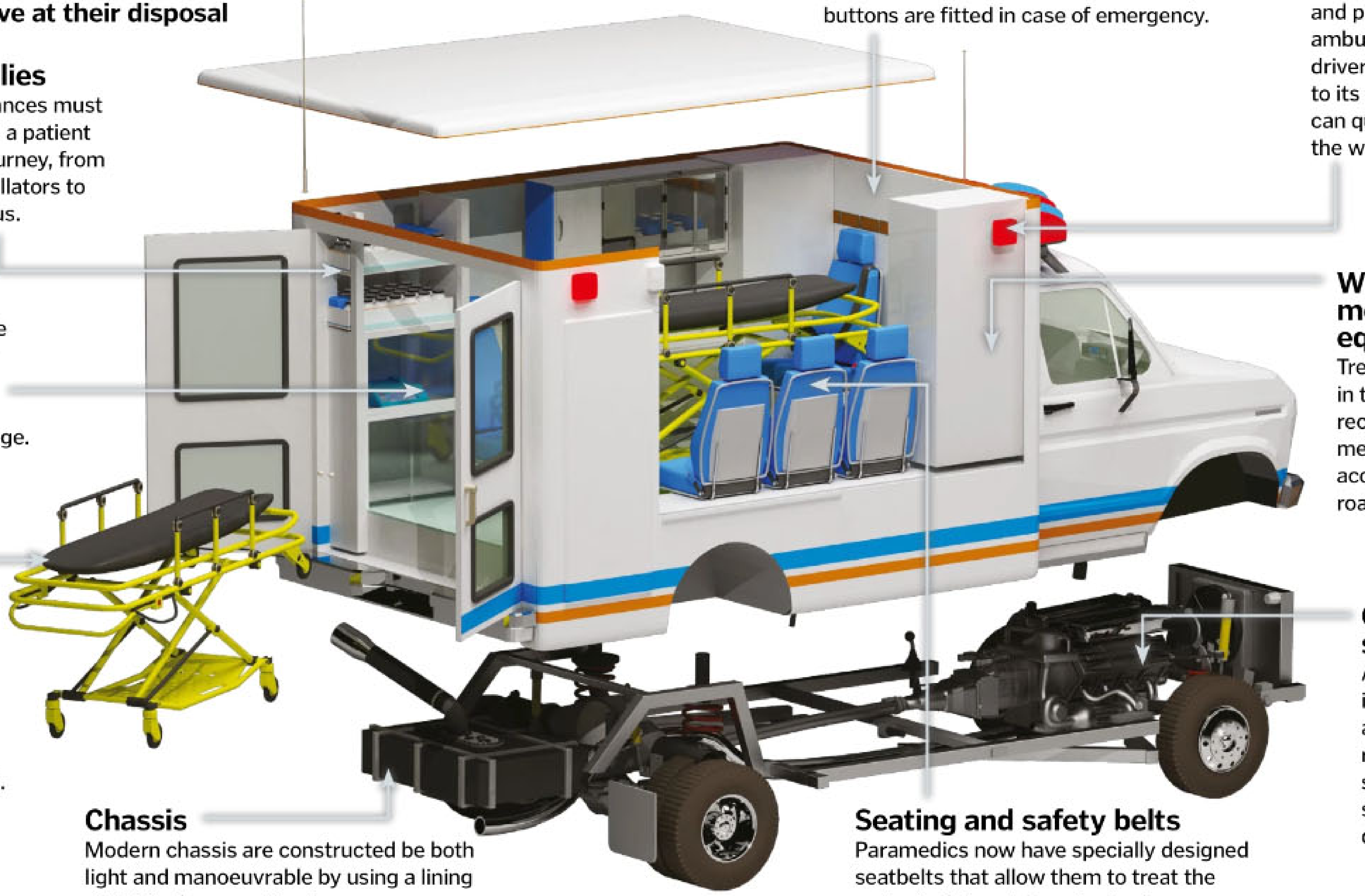
The role of an ambulance isn't just to transport patients to hospital. Now, the vehicle must be capable of accessing remote areas and treating patients effectively on the go. Paramedics have the equipment to assess and treat the injured on the scene and while the vehicle is on the road. This gives the patient the best chance of survival even before entering the hospital ward.

Current ambulances come fully loaded with defibrillators and can administrate oxygen and monitor the heart. The wheels and suspension have also been improved to allow off-road routes to be taken if there is congestion on the journey to the hospital. The LifeBot 5 is one device that has taken mobile healthcare that step further. Developed by the US Army, its motto is 'saving lives in real-time' and the telemedicine system comes equipped with a live link to a doctor in the nearest hospital. This allows the hospital to make more accurate assessments of the patient's condition and to prepare the ward for any surgery that may be required.

Despite all the modern upgrades, reaching the hospital in the quickest time is still the key objective. Today's vehicles come complete with a device that can change red traffic lights to green at certain intersections and use the best GPS and mapping systems available. These aids will prevent the motorist from driving recklessly and reduces shake and vibration from the road. This will enable more intricate and efficient treatments to be undertaken during the way to the hospital.

The modern ambulance

The medicines and equipment that paramedics have at their disposal



Medical supplies
All modern ambulances must contain everything a patient could need on a journey, from medicine to defibrillators to breathing apparatus.

Interior
The surfaces inside an ambulance are easy to clean for greater control of infection and spillage.

Stretcher
Stretchers are designed to comfortably transport the patient from the scene to hospital and can be wheeled or carried.

Chassis
Modern chassis are constructed be both light and manoeuvrable by using a lining of felt to dampen vibrations.

Communication
Ambulance staff communicate within the vehicle via hands-free audio links and panic buttons are fitted in case of emergency.

Lights
The bright flashing lights and piercing siren of an ambulance alert other drivers and pedestrians to its presence so they can quickly get out of the way

Wireless medical equipment
Treatment carried out in the ambulance is recorded to help medics operate accurately while on the road to the hospital.

Computer system
A 'black box' is installed on modern ambulances to record the driver's speed, handling, signalling and overall driving safety.

Seating and safety belts
Paramedics now have specially designed seatbelts that allow them to treat the patient while safely restrained.

Law enforcement from the sky: Meet the police drones

UAVs or unmanned aerial vehicles have now spread their wings to the world of policing. Acting as the eye in the sky for police forces the world over, drones such as the Qube are rapidly becoming more and more important. Ready for flight in less than five minutes, the Qube can be dispatched quickly to track the whereabouts of a getaway vehicle or scout ahead prior to a raid or search. The bird's-eye view of a drone will give officers an alternative viewpoint so they can respond to a distress call more efficiently and study evidence and forensics in more detail. With thermal-imaging capabilities, the Qube can be sent ahead to seek out criminals without putting lives at risk. UAVs usually operate at an altitude of between 30 and 150 metres (100 and 500 feet) but can also come closer to the ground and be utilised as a crowd-control device or in bomb disposal.

Future police cars

Meet the cars that will become part of an effective urban pursuit force

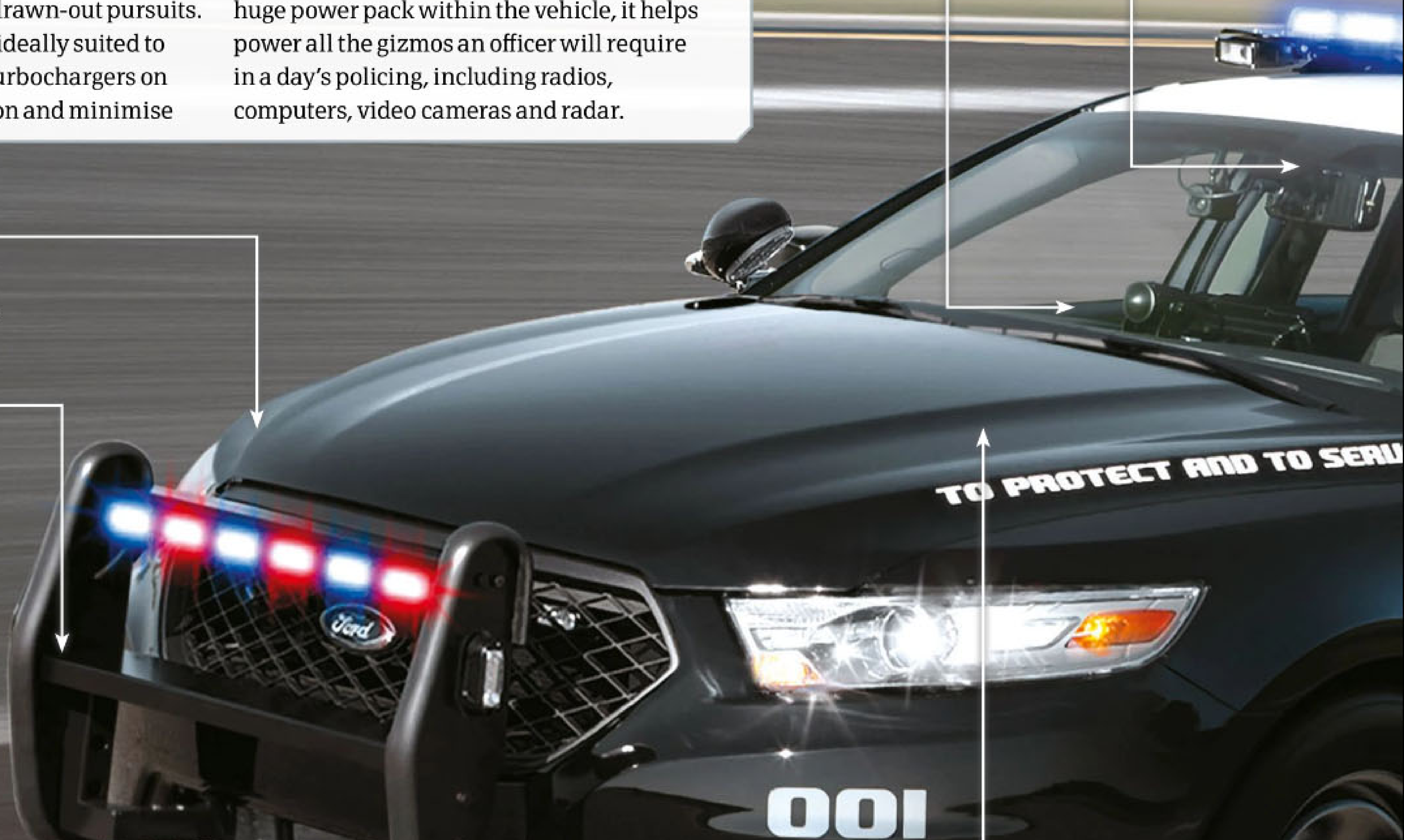
As well as looking sleek from the outside, the Interceptor is packed with state-of-the-art technology. The driver and passengers are protected by the sturdy Ford SPACE (Side Protection And Cabin Enhancement), which is both tough and comfortable. This system comes complete with a modern type of air bag that deploys between the passenger's head and the car window to give crucial protection in rollover collisions.

The Interceptor comes in two models: Sedan and Utility. Both are formidable adversaries to criminal activity with the Utility the slightly larger model that can carry more equipment and technology for longer, drawn-out pursuits. Both vehicles' drivetrain is ideally suited to 24-hour policing. The two turbochargers on board maximise acceleration and minimise turbo lag, meaning there is no hesitation when responding to an emergency call. This is part of a high-pressure direct-injection fuel system that makes the award-winning Ford 3.5-litre EcoBoost engine as efficient as possible while producing 365 horsepower (272 kilowatts).

All this power would be pointless if it wasn't for the all-wheel-drive system (AWD) that upholds the Interceptor's handling at high speeds and in tough corners. Most cars in today's market boast good power and handling, so what does the Interceptor have that civilian cars don't? The answer lies in the 220-amp alternator on board. Essentially a huge power pack within the vehicle, it helps power all the gizmos an officer will require in a day's policing, including radios, computers, video cameras and radar.

Inside the Interceptor

Discover the tech that makes the Interceptor the way forward for police cars



Personal Safety System
Sensors operate the air bags so they can determine the size of a collision and distinguish between firefights and crashes.

Cooling system
An optimal amount of air flows through the car so it can cope with the heat generated during a typical day.

Structure and strength
Using safety-cell construction technology, the Interceptor has strategically placed crumple zones that absorb the energy of a crash.

Crash testing
The chassis of an Interceptor is so strong that it can pass a rear-end crash test at 120km/h (75mph) with flying colours.

Engine
Using Ford's own EcoBoost technology, the car's 3.5l V6 engine produces 365bhp (272kW) and has two turbochargers to prevent lag.

Wheels
An Interceptor is designed to maintain law and order 24 hours a day with its high strength five-spoke steel wheels.

The Ford Interceptor aims to meet the increasing demand for power and safety for law-enforcement vehicles

DID YOU KNOW? *The Interceptor uses tethers to strengthen door hinges when they need to be flung open in a chase or firefight*

Dubai's supercar cops

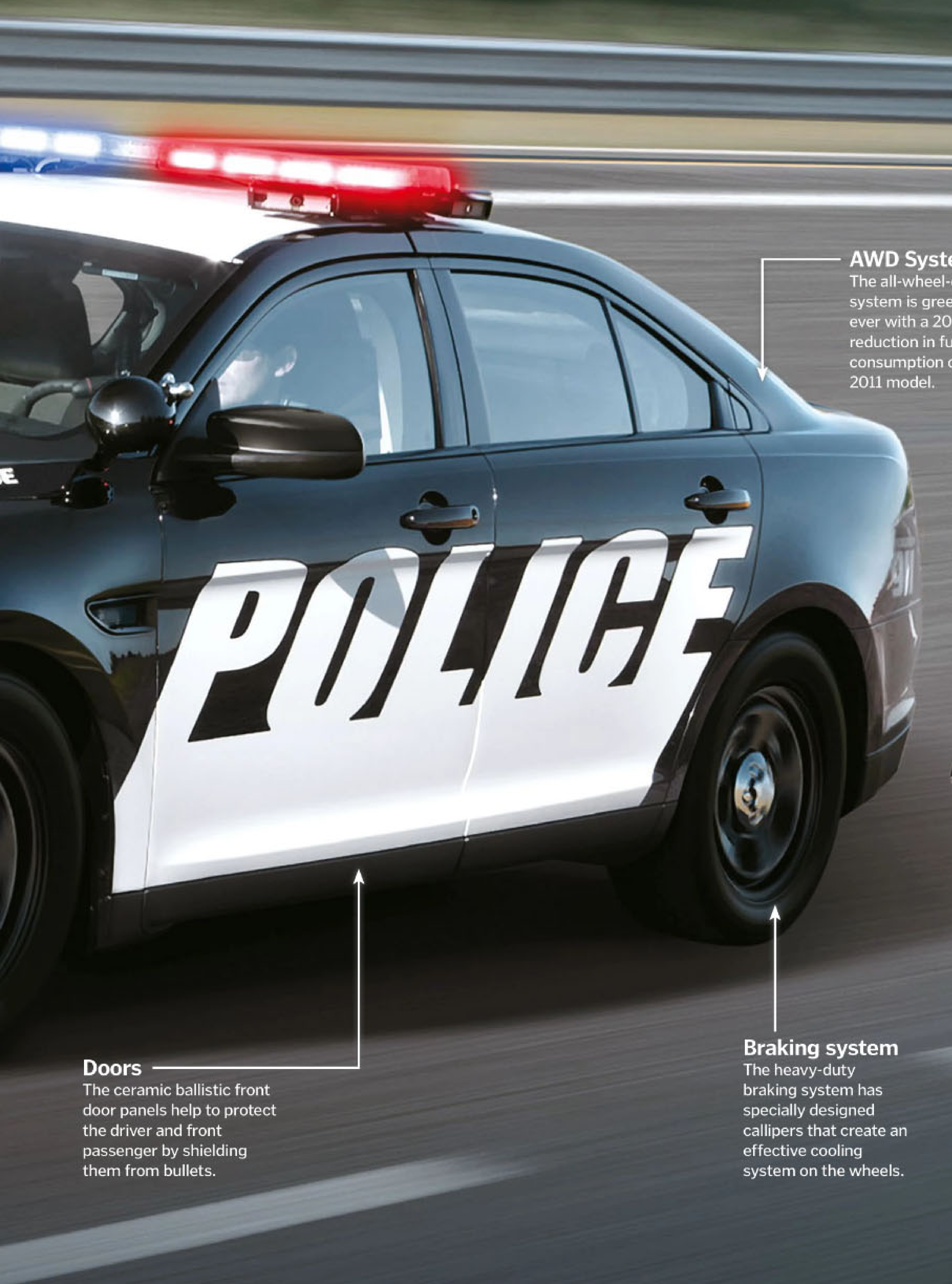
Whether it's the tallest building in the world or an artificial archipelago shaped like a palm tree, Dubai doesn't trade in half measures. The police force is no different, with its supercars the envy of both petrolheads and other cops around the world. The fleet has everything from Lamborghini Aventadors to Bugatti Veyrons and Bentley Continentals. The Lamborghini is particularly impressive, boasting a top speed of 350 kilometres (217 miles) per hour in its 6.5-litre V12 engine. The cars are as much of a tourist attraction as they are a law-enforcement vehicle. Dubai isn't exactly a global hotbed for street crime and many onlookers feel it is just a publicity stunt for the 2020 World Expo, which the city will host. However, if a happy medium between performance and reliability can be found, the police cars of the future may not be all that different to the ones we currently see patrolling this modern city's streets.

Lawbreakers will have to pack some serious speed to out run Dubai's police force!

Green policing on two wheels

If an Interceptor isn't available, you can always hop on a motorcycle. As adept off road as it is on the streets, the Zero SP is quiet and exhaust free. Its electric powertrain gives it a top speed of 158 kilometres (98 miles) per hour and a range of 286 kilometres (178 miles) and it can recharge anywhere with a connection to the main grid. Its silence and lack of emissions mean the motorcycle can be used in tight situations such as compact city streets and dense pedestrian areas. Rather than go in all guns blazing, silent patrols offer an alternative solution to security and law enforcement. Its lightweight chassis and regenerative braking make it extremely manoeuvrable, allowing the bike to be inconspicuous and have the element of surprise when on the trail of a suspect. The Zero SP promotes a new way of policing that can undertake patrols effectively while being environmentally friendly at the same time.

The Zero SP is developed by Zero Motorcycles and promises an electric, exhaust-free way of policing



AWD System
The all-wheel-drive system is greener than ever with a 20 per cent reduction in fuel consumption over the 2011 model.

Doors
The ceramic ballistic front door panels help to protect the driver and front passenger by shielding them from bullets.

Braking system
The heavy-duty braking system has specially designed callipers that create an effective cooling system on the wheels.

Fire engines

The Oshkosh Striker is a rough, tough fire truck coming to an airport near you

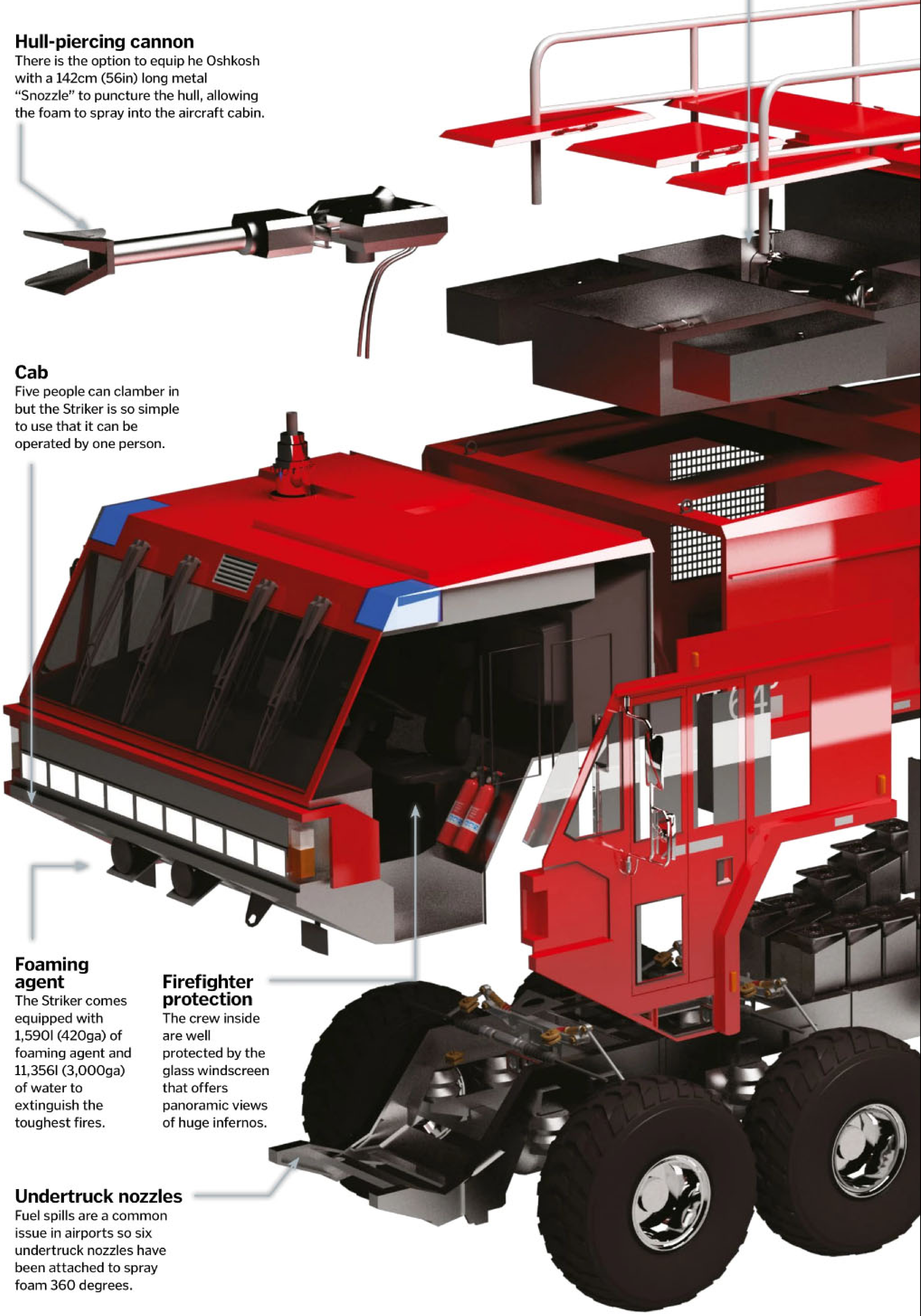
Aviation fuel is extremely flammable so it is essential that a top-of-the-range fire engine is always on hand to fight the flames at airports across the globe. Enter the Oshkosh Striker. First produced in 2001, the vehicle had a a bit of a revamp in 2010 and has now become the leading light in its class. Its combination of flame- smothering foam and quick acceleration make it a must at airports where smoke can choke a plane cabin in minutes. It has become so popular that it is used as the response vehicle of choice for US Air Force bases and even the White House.

The Striker's powerful foam and water cannons and a rapid response time make it a powerful all-round firefighting machine. To achieve maximum acceleration, engineers removed unnecessary parts and replaced heavy materials with lighter ones for more speed. Small but vital additions such as all-wheel suspension, a high reach extendable turret and an intercooled engine make it a match for the strongest of infernos. Its simple control system combined with its high-visibility windows make it easy to run and service so the vehicle is always available to fight fire.

There are three different models of Striker: the 4x4, 6x6 and 8x8. Each one is larger and better equipped than the last, but all can be deployed to race down the runway in the face of an airport fire. With extra terminals springing up at airports worldwide and a constant stream of planes travelling through them, the Striker has never been in higher demand.

The Oshkosh Striker

US company Oshkosh has packed all its technological expertise into this monster of a fire engine



Cameras
To concentrate the water cannons on the epicentre of a fire, infrared cameras are used from the safety of the cabin.

Hull-piercing cannon
There is the option to equip he Oshkosh with a 142cm (56in) long metal "Snozzle" to puncture the hull, allowing the foam to spray into the aircraft cabin.

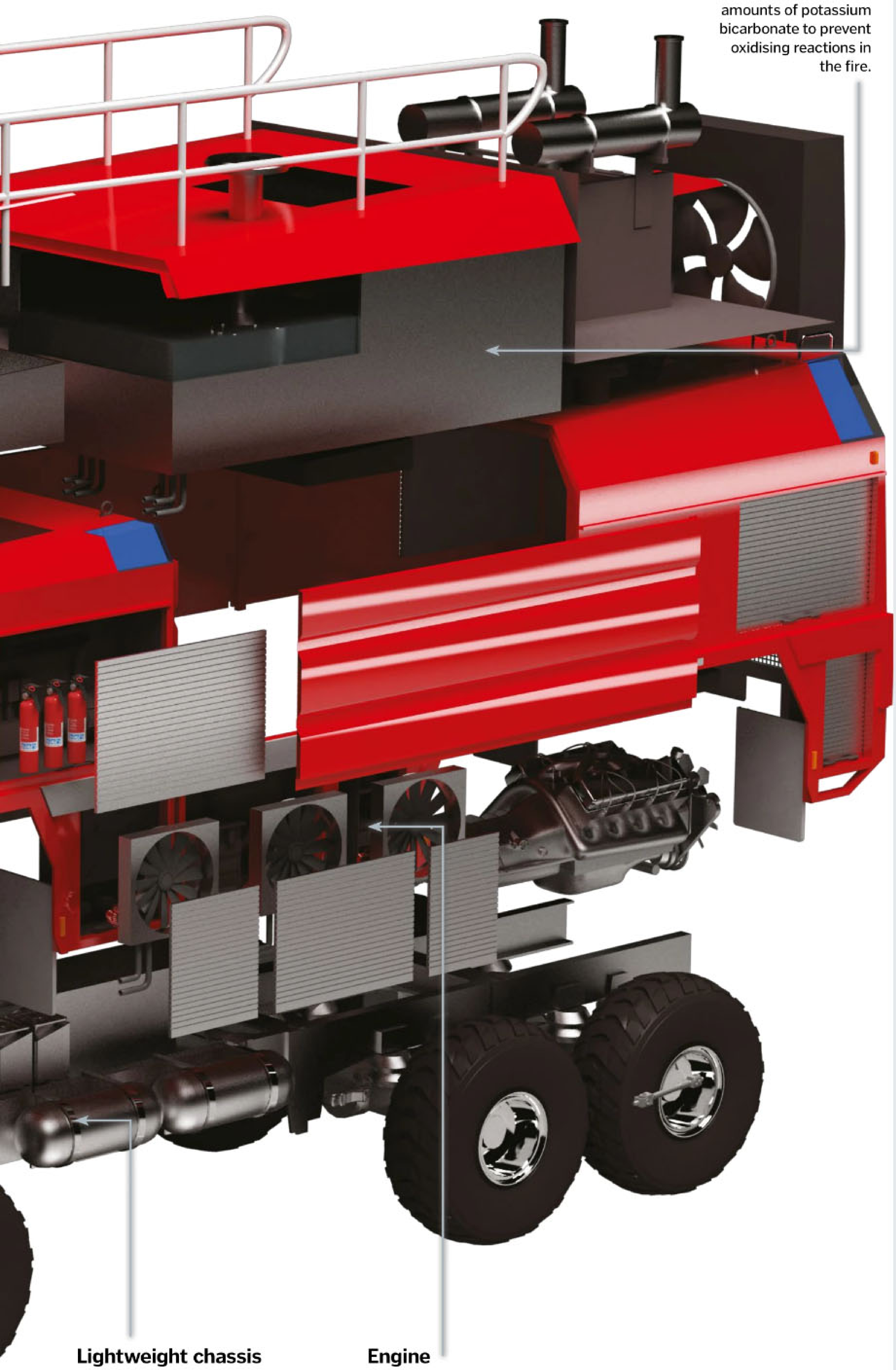
Cab
Five people can clamber in but the Striker is so simple to use that it can be operated by one person.

Foaming agent
The Striker comes equipped with 1,590l (420ga) of foaming agent and 11,356l (3,000ga) of water to extinguish the toughest fires.

Firefighter protection
The crew inside are well protected by the glass windscreen that offers panoramic views of huge infernos.

Undertruck nozzles
Fuel spills are a common issue in airports so six undertruck nozzles have been attached to spray foam 360 degrees.

DID YOU KNOW? *Aviation fuel burns at a scorching 1,370°C (2,500°F) so fires can quickly engulf whole buildings with thick smoke*



Chemical tank
As well as foam, the Striker holds high amounts of potassium bicarbonate to prevent oxidising reactions in the fire.

Lightweight chassis
It may weigh 44 tons, but the Oshkosh doesn't hang about, as it is constructed out of custom-designed light materials.

Engine
The V8 engine powers both the drivetrain and the cannons and uses computers to adjust the power to different situations.

Hop on the electric, exhaust-free police motorcycle

Interview with Scot Harden, VP of Global Marketing for Zero Motorcycles

What was the inspiration behind Zero?
Our mission is to transform two-wheeled recreation and transportation through our innovative, high-tech motorcycles. We aspire to provide all the attributes you normally expect from the motorcycling experience, the sense of adventure, thrill, freedom and personal fulfilment without any of the hassles associated with motorcycles. No heat, no vibration, no emissions and no sound.

How will police forces around the world utilise it in their fleets?
Over 50 agencies in the US are using Zero motorcycles as well as several high-profile international police/security organisations, including Hong Kong and Colombia. Our motorcycles are used for routine patrol, crowd control, event and private security efforts. The stealth nature of our products allows authorities to arrive on the scene of criminal activity unannounced and to patrol areas otherwise inaccessible. The low maintenance costs provides additional motivation to adopt our products. Currently Zero-fleet motorcycles are being used by police, military, university campus, fire departments and private security forces.

What technology is used in the Zero?
We use a proprietary drive train that has been developed internally by Zero and features the most energy-dense battery system available today. Our ZForce powertrain consists of three main components; the motor, battery and controller. Battery technology is based on lithium-ion chemistry.

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Virtual reality

VIRTUAL REALITY

From training doctors to planning military ops, discover how VR is set to change the world

DID YOU KNOW? *Jack White has an app that plays a 360-degree video of one of his gigs when viewed using Google Cardboard*

This is the year when virtual reality changes life as we know it. That's according to research from Deloitte, which predicts sales to reach $1 billion (£700 million) in 2016 when the Oculus Rift and headsets from Sony, HTC and PlayStation are finally released.

"Head-mounted displays are going to be like toasters," says Dr Albert 'Skip' Rizzo, Director of Medical Virtual Reality at the University of Southern California's Institute for Creative Technologies. "You might not use it every day but everybody's going to have one." Whether you want to step inside the video games you play, or explore far-flung places from the comfort of your sofa, VR is set to usher in an entirely new era of home entertainment.

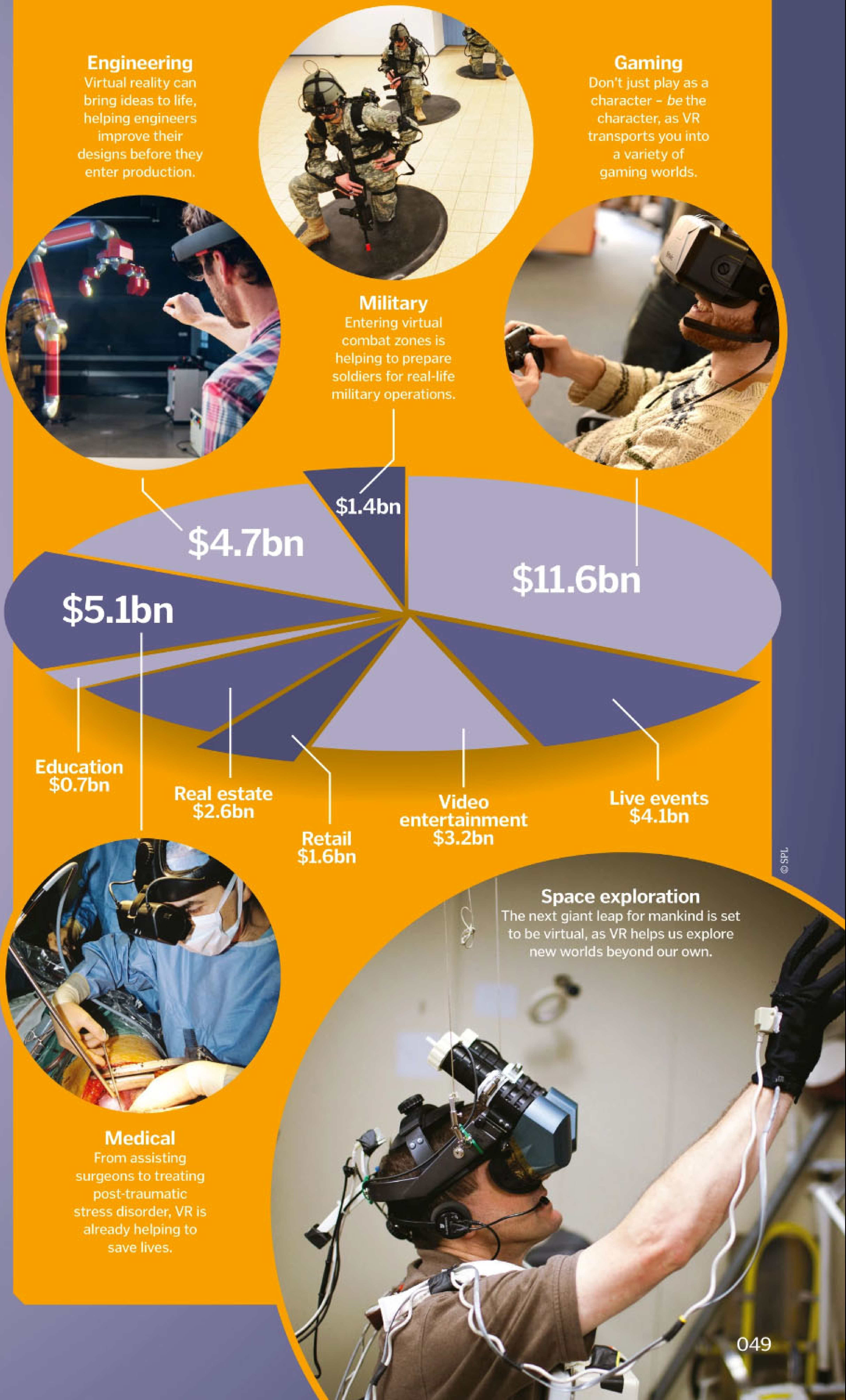
For some people though, VR is already drastically changing day-to-day life, as the technology has a wide range of uses that extend far beyond gaming. From performing remote surgeries and treating medical conditions, to training soldiers and planning military operations, hundreds of groundbreaking applications are currently being explored.

But while this tech is getting most of us excited, there are some that are left feeling cybersick. The symptoms are similar to motion sickness and it's caused by a mismatch of sensory inputs. The brain expects things to be in sync, but in a simulated scenario, you observe movement – like the rickety track of a rollercoaster – but you don't feel it. It's the opposite of traditional motion sickness, which occurs when you feel movement in your inner ear, but you don't see it. The result is the same though, and it's a big obstacle to making virtual the new reality.

> *"Hundreds of groundbreaking applications for VR are currently being explored"*

Receiving feedback other than visuals and sound is another issue, as it is difficult to recreate a sense of touch that enables you to fully interact with the world around you. On top of this, virtual reality is currently a solitary experience, as others cannot share what you're viewing through the headset. However, with developers already working on ingenious solutions, such as haptic feedback gloves, wireless tracking technology and programmes that can create avatars of your friends, the virtual future is set to be one of endless possibilities.

Predicted uses of VR by the year 2025



Engineering
Virtual reality can bring ideas to life, helping engineers improve their designs before they enter production.

Military
Entering virtual combat zones is helping to prepare soldiers for real-life military operations.

Gaming
Don't just play as a character – *be* the character, as VR transports you into a variety of gaming worlds.

Medical
From assisting surgeons to treating post-traumatic stress disorder, VR is already helping to save lives.

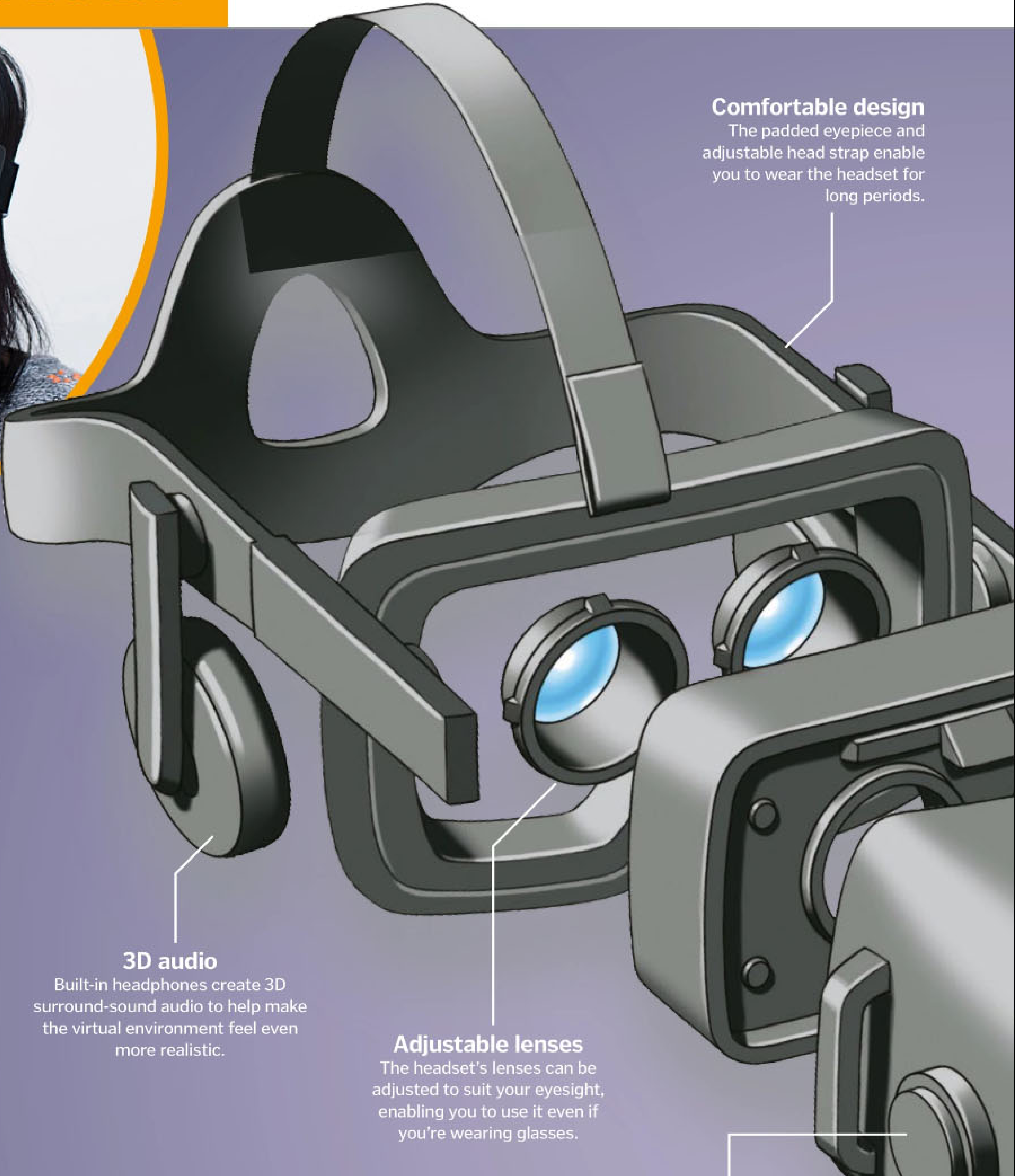
Space exploration
The next giant leap for mankind is set to be virtual, as VR helps us explore new worlds beyond our own.

© SPL

How does VR work?

The kit that transports you into virtual worlds

Several mobile headsets that require your smartphone to work are already available, but it is the high-end connected kits that will really show off what VR can do. The Oculus Rift and HTC Vive are the current front-runners, with the former already available to pre-order for around $600 (£425) and expected to start shipping in March. These headsets feature built-in displays, are powered via a cable and require external sensor systems to track your movements.



Comfortable design
The padded eyepiece and adjustable head strap enable you to wear the headset for long periods.

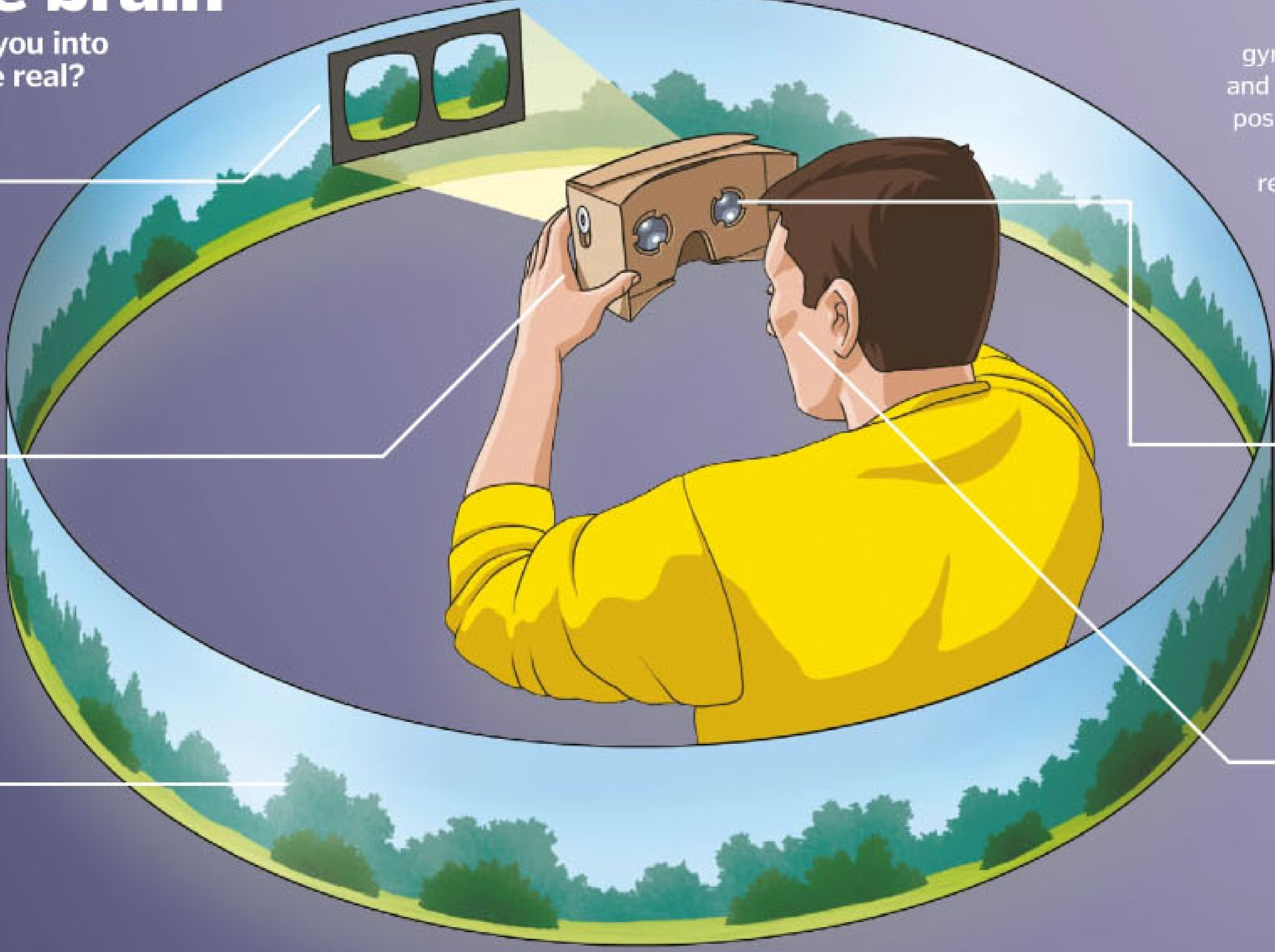
3D audio
Built-in headphones create 3D surround-sound audio to help make the virtual environment feel even more realistic.

Adjustable lenses
The headset's lenses can be adjusted to suit your eyesight, enabling you to use it even if you're wearing glasses.

Head trackers
Sensors including a gyroscope, accelerometer and magnetometer track the position of your head so the virtual world can be rendered appropriately.

Tricking the brain

How do VR headsets fool you into thinking virtual worlds are real?



Stereoscopic display
VR headsets use dual lenses or a split-screen display to put a slightly different image in front of each eye, recreating your normal stereoscopic vision.

Total immersion
The headset blocks out any other light, and headphones can be worn to block out sound, eliminating any distractions from the real world.

Smooth footage
The VR footage needs to refresh at a high frame rate to avoid any noticeable flickering that could leave you feeling nauseous.

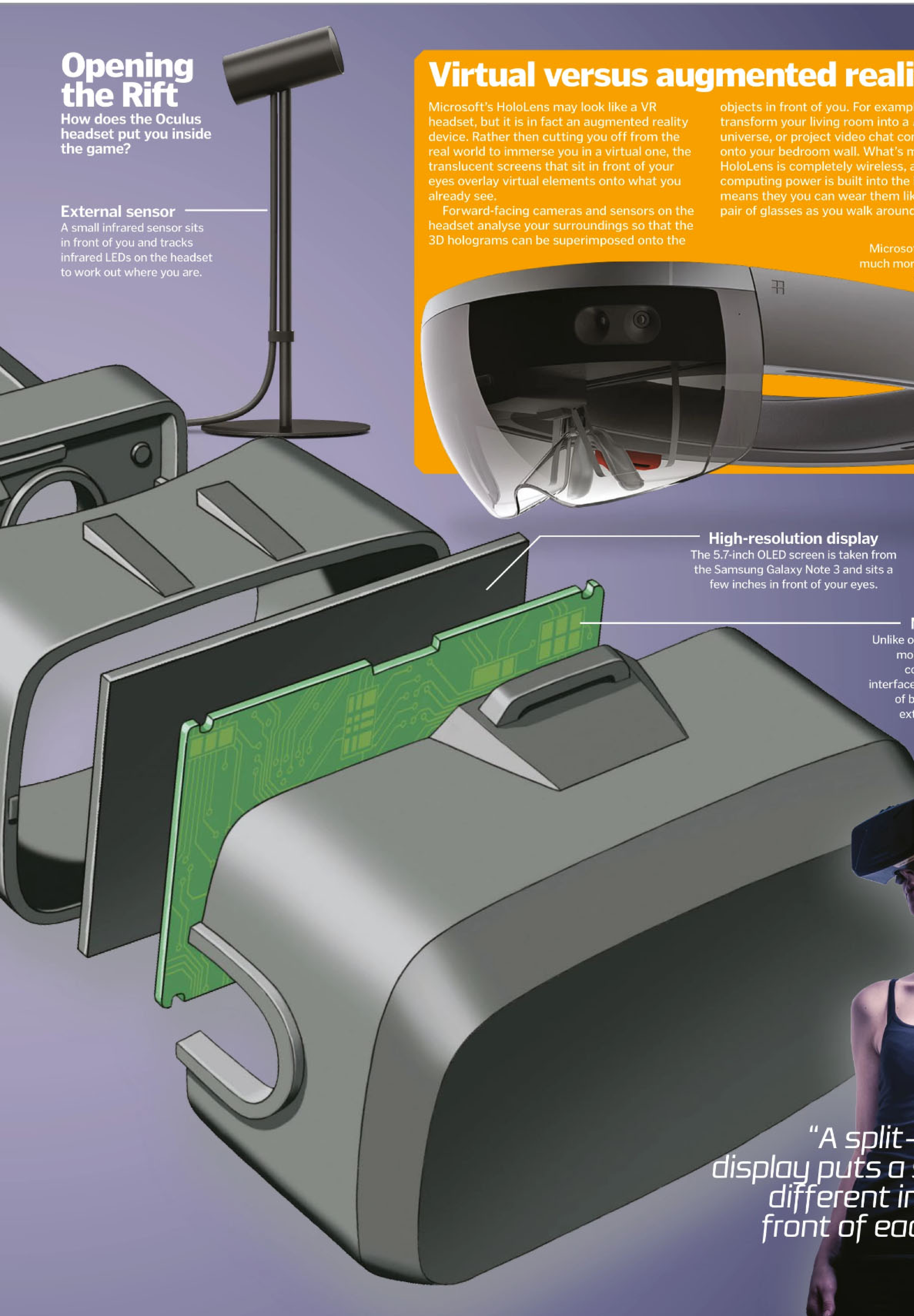
Motion tracking
Built-in accelerometers and gyroscopes, or external sensors, work out the position of your head so the image can be adjusted accordingly as you look around.

Normal vision
When you see the world, each eye records the scene from a slightly different angle and your brain puts the two views together to create one 3D image.

DID YOU KNOW? *Social media giant Facebook bought Oculus Rift for $2 billion (£1.3 billion) in 2014*

Opening the Rift

How does the Oculus headset put you inside the game?



External sensor
A small infrared sensor sits in front of you and tracks infrared LEDs on the headset to work out where you are.

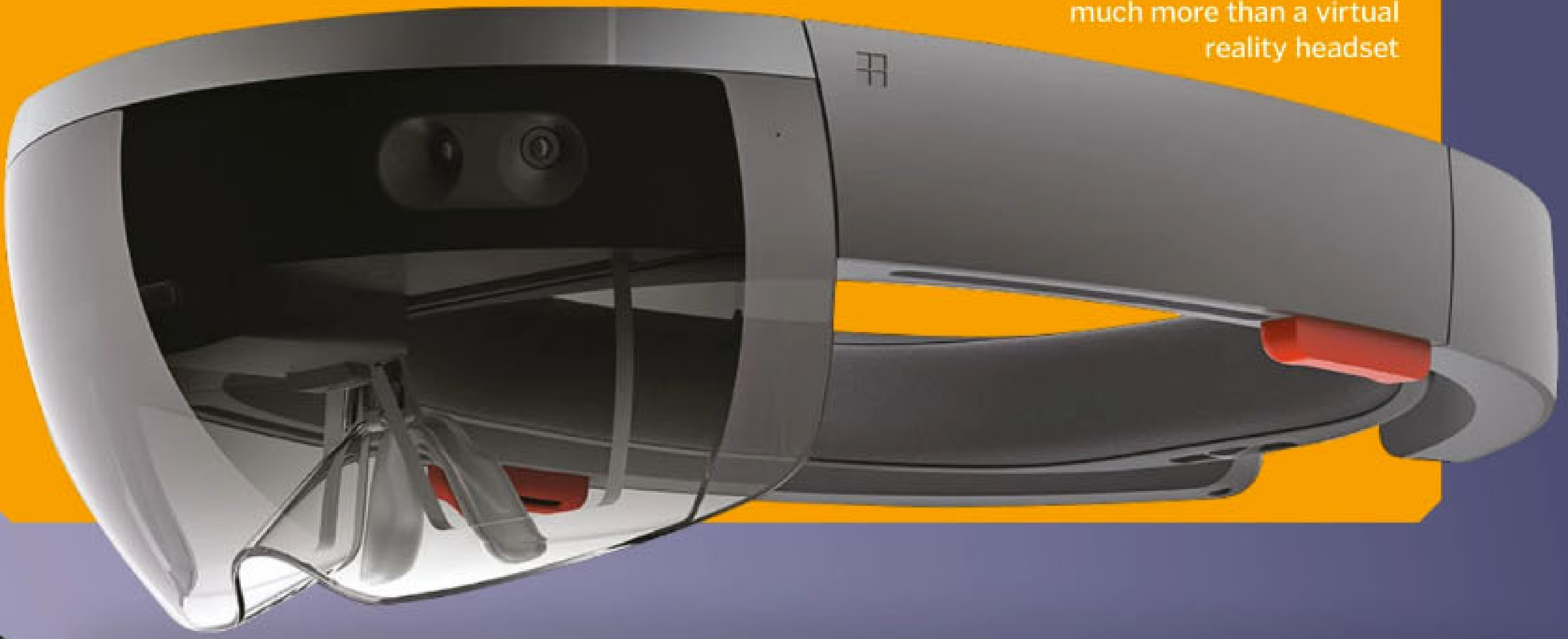
High-resolution display
The 5.7-inch OLED screen is taken from the Samsung Galaxy Note 3 and sits a few inches in front of your eyes.

Motherboard
Unlike on previous Oculus models, the chip that controls the display interface is built in instead of being located in an external control box.

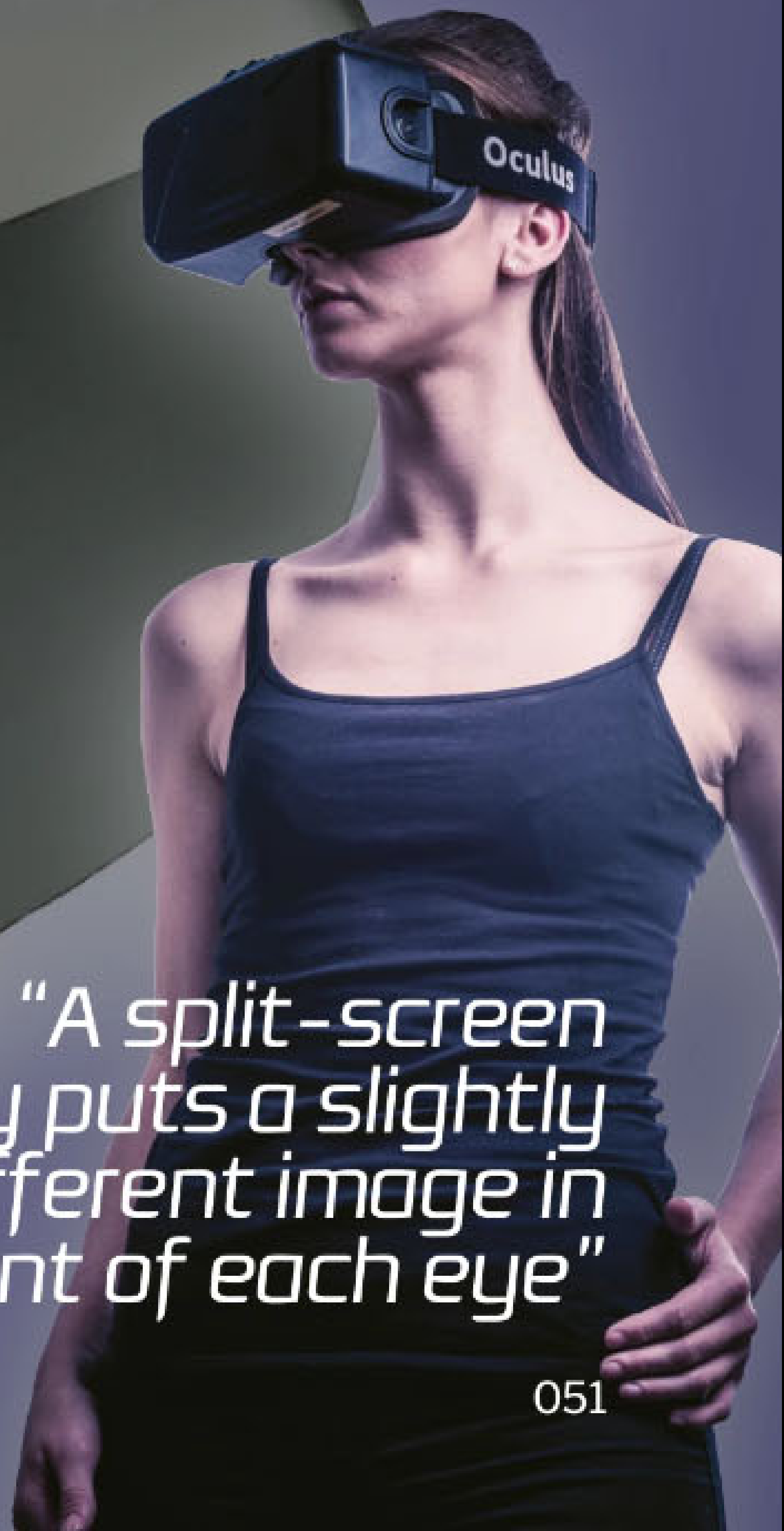
Virtual versus augmented reality

Microsoft's HoloLens may look like a VR headset, but it is in fact an augmented reality device. Rather then cutting you off from the real world to immerse you in a virtual one, the translucent screens that sit in front of your eyes overlay virtual elements onto what you already see.

Forward-facing cameras and sensors on the headset analyse your surroundings so that the 3D holograms can be superimposed onto the objects in front of you. For example, you can transform your living room into a *Minecraft* universe, or project video chat conversations onto your bedroom wall. What's more, the HoloLens is completely wireless, as all of the computing power is built into the headset. This means they you can wear them like a regular pair of glasses as you walk around.



Microsoft's HoloLens is much more than a virtual reality headset



> *"A split-screen display puts a slightly different image in front of each eye"*

Let VR entertain you

Get ready to redefine the meaning of fun

Gaming and other forms of entertainment have been the main driving force fuelling the development of this technology. It's predicted to be the main function for VR in the coming years, and already a wide range of accessories have been designed to enhance the experience. The Virtuix Omni is a motion platform that enables you to walk or run to control your avatar in a virtual world, as opposed to just staying seated and turning your head while you tap at an Xbox controller. Then there's Oculus Touch, a pair of wireless controllers that let you feel as though your virtual hands are your own, meaning you can reach out and interact with objects in the game.

Virtual hands

The tech that gives you the power to reach into the game

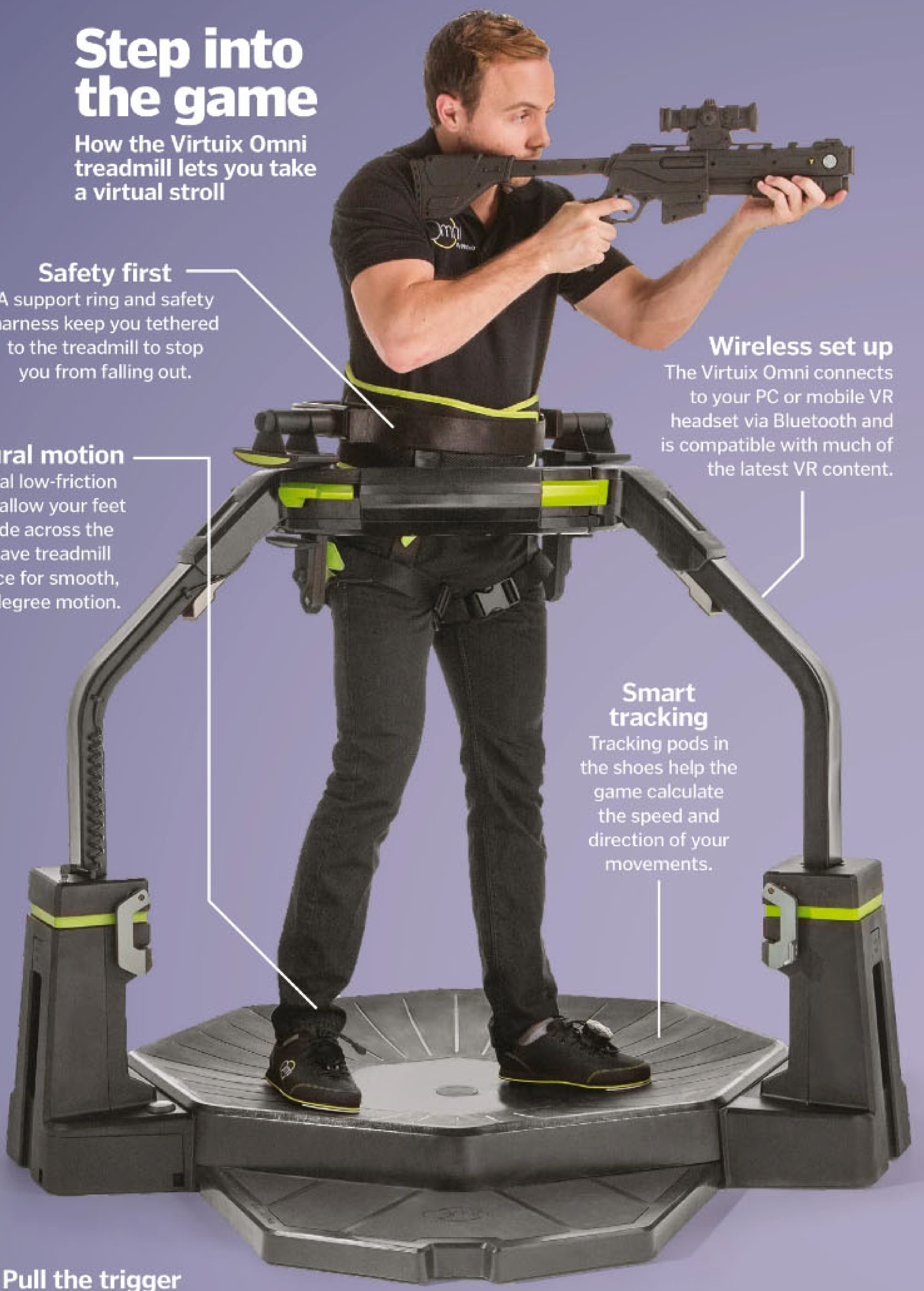
Haptic feedback
The controllers are able to deliver feedback when you interact with objects in the virtual world, helping them feel real.

Cable-free
The wireless controllers are tracked by the Rift system using infrared LEDs and sensors, so it knows where your hands are.

Pull the trigger
A 'hand trigger' input mechanism replicates the feeling of firing a gun for a fully immersive first-person shooter experience.

Step into the game

How the Virtuix Omni treadmill lets you take a virtual stroll



Safety first
A support ring and safety harness keep you tethered to the treadmill to stop you from falling out.

Natural motion
Special low-friction shoes allow your feet to glide across the concave treadmill surface for smooth, 360-degree motion.

Wireless set up
The Virtuix Omni connects to your PC or mobile VR headset via Bluetooth and is compatible with much of the latest VR content.

Smart tracking
Tracking pods in the shoes help the game calculate the speed and direction of your movements.

> "Gaming is predicted to be the main function for VR"

VR coasters and virtual cinemas

You can already ride virtual rollercoasters using a VR headset – so long as you can stomach the slightly nauseous feelings – but one of the UK's biggest theme parks is now taking things a loop further. The new Galactica rollercoaster at Alton Towers requires each rider to pop on a VR headset, making them feel as though they are flying through space while they are in fact hurtling along a track at 75 kilometres per hour.

For the adrenaline averse, there's virtual cinema – apps that recreate the traditional movie theatre experience. Already available for the Oculus and Google Cardboard, they allow you to choose a seat and then enjoy the film without any annoying distractions from popcorn munchers. That's not all though, as film directors such as Ridley Scott are already producing VR content that will enable you to step into the films themselves.

Galactica is the world's first rollercoaster entirely customised for the full virtual reality experience

DID YOU KNOW? *The British Army is attracting new recruits by giving them a taster of army life using VR headsets*

On the battlefield

Forget Call Of Duty – how can virtual reality revolutionise real-life military operations?

Military organisations are often among the first to adopt the latest technological innovations and virtual reality is no exception. There are many potential applications for VR in combat, but British engineers from BAE Systems are working on some truly groundbreaking concepts. They are planning to create a 'mixed reality', using headsets to overlay virtual images, video feeds, objects and avatars onto footage of the operator's actual surroundings, which are recorded by a front-facing camera.

One use for this is in developing a portable command centre that can be transported in a briefcase and set up anywhere. The user would simply put on a headset and interactive gloves, and be able to monitor situations anywhere in the world. This would enable them to direct troops and even bring in artificially intelligent avatars to provide updates and advice. Another use for mixed reality is the 'wearable cockpit', a headset that overlays virtual displays onto the pilot's real-time view, enabling them to customise controls based on their own preferences and mission objectives.

As well as assisting soldiers when they are in battle, VR can also be used to train them before they get there. Headsets can be used to simulate a real-life combat zone, which can be experienced from a safe, controlled environment, keeping the soldier out of harm's way.

Of course, staying stationary during training isn't ideal, so a variety of devices have been designed to give soldiers complete freedom of movement in virtual environments. The Virtusphere is a hollow ball on wheels, which rotates in any direction as the person moves inside. Sensors communicate the user's movements to their VR headset, so their view can be updated accordingly. Alternatively, the Cybersphere is another human-sized hamster-ball, which doesn't even need a headset to create a virtual battlefield.

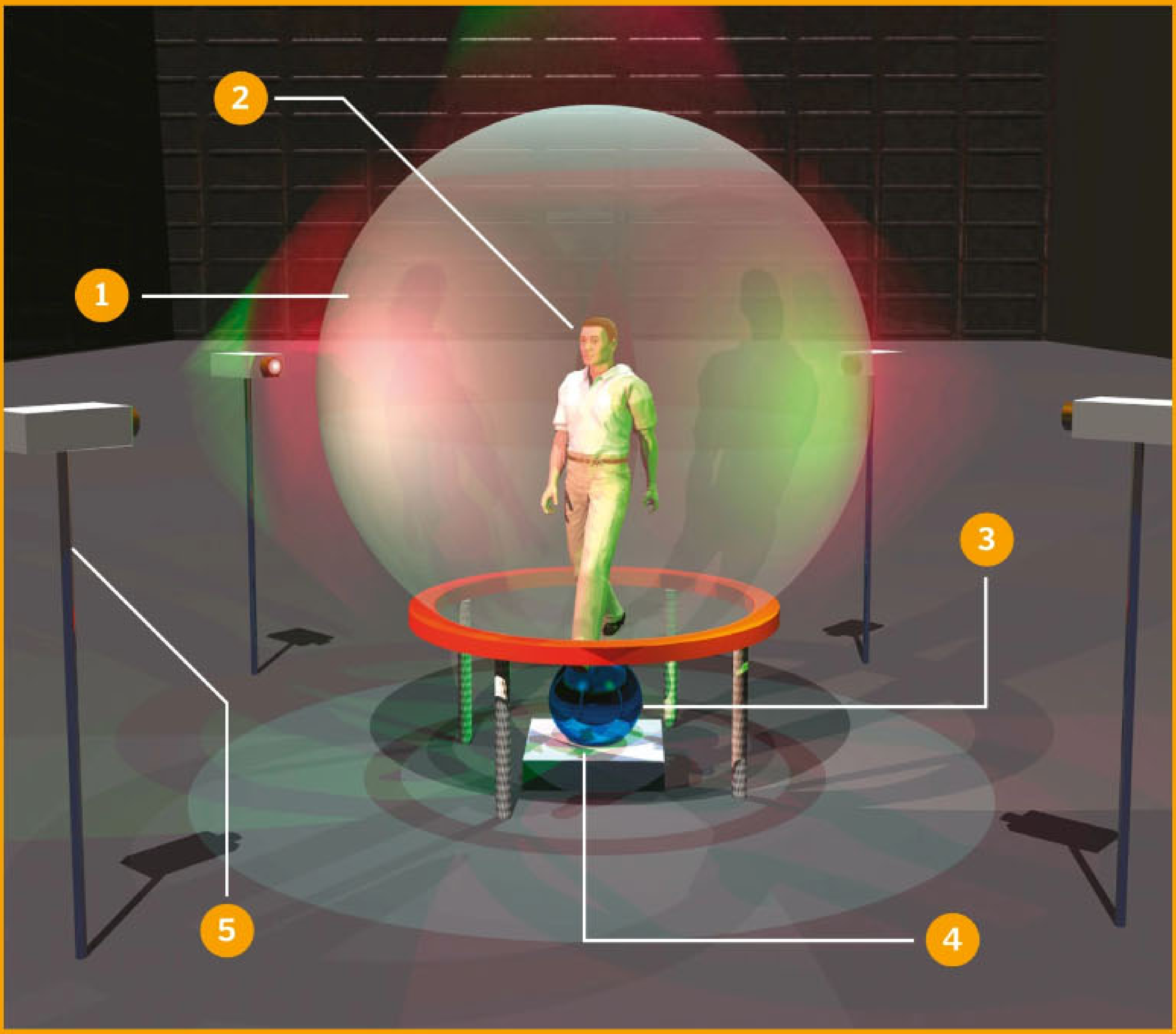
BAE Systems' wearable cockpit overlays the pilot's view with useful graphics

A portable command centre would let military personnel manage emergencies from anywhere in the world

The Virtusphere lets soldiers move freely in a virtual battlefield environment

Step into the Cybersphere

The hamster ball for humans trains soldiers for battle



1 Freedom of movement
A hollow, translucent sphere measuring 3.5 metres in diameter sits on a cushion of air, which allows it to rotate freely.

2 Rolling around
As the user walks, runs or crawls, they cause the sphere to rotate, although the structure itself remains stationary.

3 A second sphere
The movement of the large sphere is transferred to a smaller sphere; spring-loaded supports connect the two parts.

4 Motion tracking
Rotation sensors record the movements of the smaller sphere to update the images that are then seen by the user.

5 Wrap-around view
Images of a virtual world are projected onto the interior walls of the sphere, so the user inside does not need to wear a headset.

© SPL

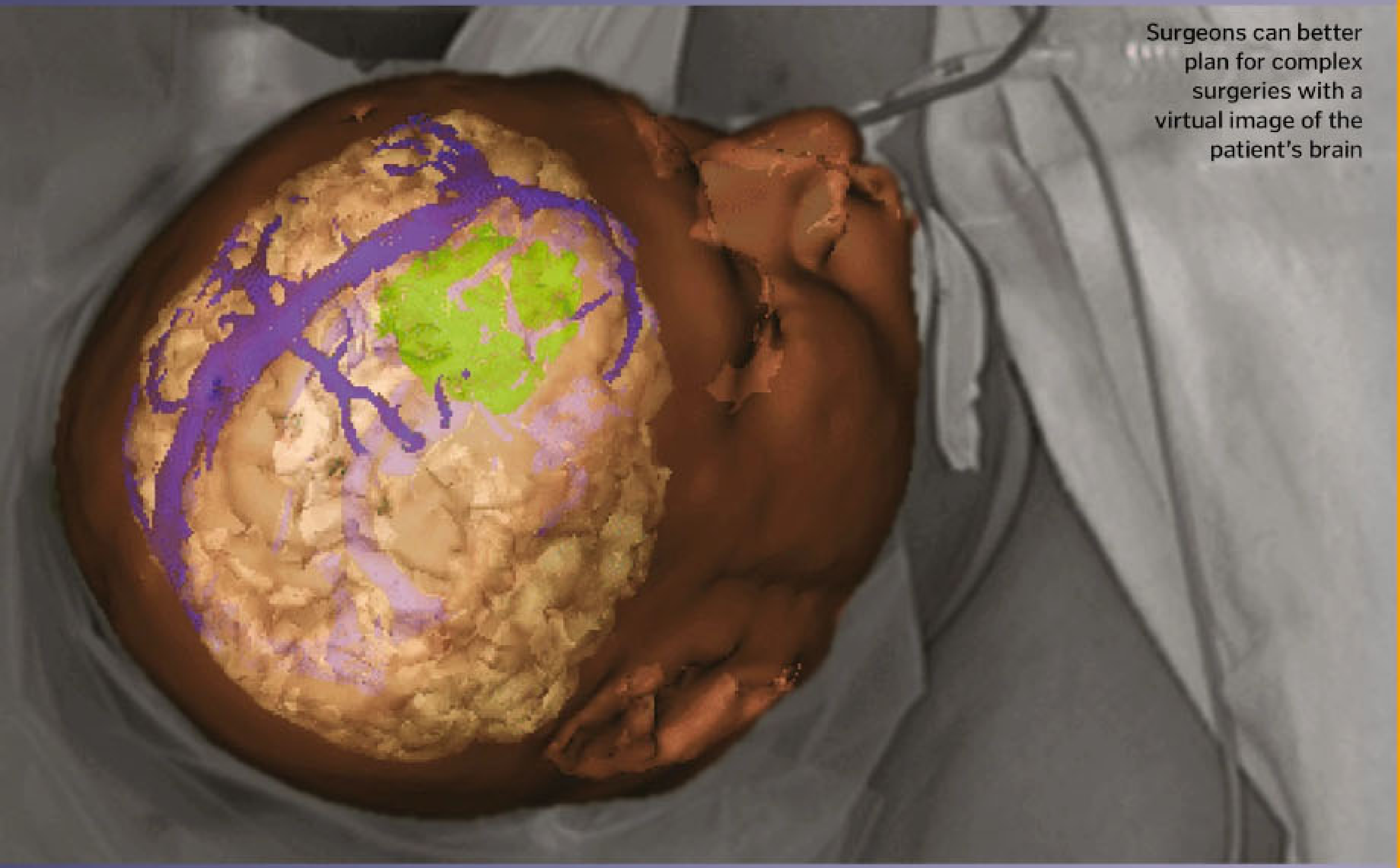
Is VR good for your health?

The groundbreaking applications in healthcare

In a recent report about the growth of virtual and augmented reality, investment banking firm Goldman Sachs estimates that the industry will be worth $80 billion by the year 2025. It also predicts that, aside from video games, healthcare will be one of the biggest applications for the technology.

Already, VR is being used to train surgeons, allowing them to practise complex procedures on a virtual patient before they get to the real thing, and it can even be used to conduct robotic surgeries too. Wearing a head-mounted display, the surgeon can control a robotic arm that is capable of making smaller, more delicate movements than human hands could ever manage, plus it enables them to operate on a patient remotely from an entirely separate location.

There is also a wide range of applications for which virtual reality can be used to treat patients directly. For example, VR can enable people with phobias and post-traumatic stress disorder to face their fears in a virtual world, in order to help combat them in the real one.


Surgeons can better plan for complex surgeries with a virtual image of the patient's brain

Education

Discover how VR can really bring lessons to life

Imagine being able to visit outer space or walk with dinosaurs instead of just reading about them in a textbook. Virtual reality could transform the way subjects are taught in the classroom, and one company is already developing a library of experiences that can educate students of all ages.

"Virtual reality offers a new way to view the world," says David Whelan, CEO of Immersive VR Education. "For the first time in humanity we can walk a mile in other people's shoes." The Apollo 11 experience, for example, lets you step onto the Moon as Neil Armstrong. "This is much more powerful than reading about the moon landing in a book," he adds. "Virtual reality has the potential to revolutionise education in the same way that reading and writing did thousands of years ago."

Virtual reality can enable students to experience events from history and impossible-to-visit places

Virtual treatments

At the University of Southern California's Institute for Creative Technologies, Dr Albert 'Skip' Rizzo and his team are using virtual reality for a number of game-changing clinical purposes. We spoke to him about their amazing work...

How are you using VR to treat post-traumatic stress disorder (PTSD)?
One of the typical treatments for PTSD is prolonged exposure therapy. You ask the person to close their eyes and imagine the trauma that they went through as if it's happening right then and get them to describe it to you. By doing that repetitively in a safe and supportive environment, eventually the anxiety that it provokes in them diminishes. It sounds kind of counterintuitive at first but there's actually quite a lot of research to support this. What we do with VR is simply to deliver this previous imagination-only approach in an immersive virtual reality simulation.

We have developed 14 different virtual worlds that represent a diverse range of experiences, and the clinician is able to adjust them in real-time, for example to change the time of day or introduce sound effects. The patient does exactly what they would do in traditional exposure therapy, but the clinician then tries to mimic their experience in the simulation to enhance the effects.

What other clinical VR projects are you working on?
One project is building a job interview training system for people with high-functioning autism – people that are very bright but have a difficult time with social interaction. We've built a simulation that has six different job interviewers, that can be set at three different levels, from a soft touch, nice interviewer to a more hostile interviewer that puts you ill-at-ease, giving them the opportunity to practise. We've also made virtual patients that give clinicians an opportunity to essentially mess up with a digital character before they get to a live one.

Are there limitations of the tech in this field?
The limitations right now have really diminished. I started in this game back in the early 90s, when it required a $200,000 computer, and you had bulky head-mounted displays with low resolution, limited field of view, poor tracking and primitive graphics. There was a network of people that wanted to do this work, but it was challenging because the technology really sucked.

But now the technology has finally caught up with the vision. Computing power has consistently gotten better and faster, which is needed for good rendering, and of course the games industry has driven advances in graphic development that are phenomenal. So the limits right now are the limits of our imagination and the funding to evolve these applications and test them in a consistent way.

Dr Rizzo uses virtual reality simulations to treat post-traumatic stress disorder

Virtual reality helps astronauts train for life and work in space

Space exploration

A new way to work in space and tour the Solar System

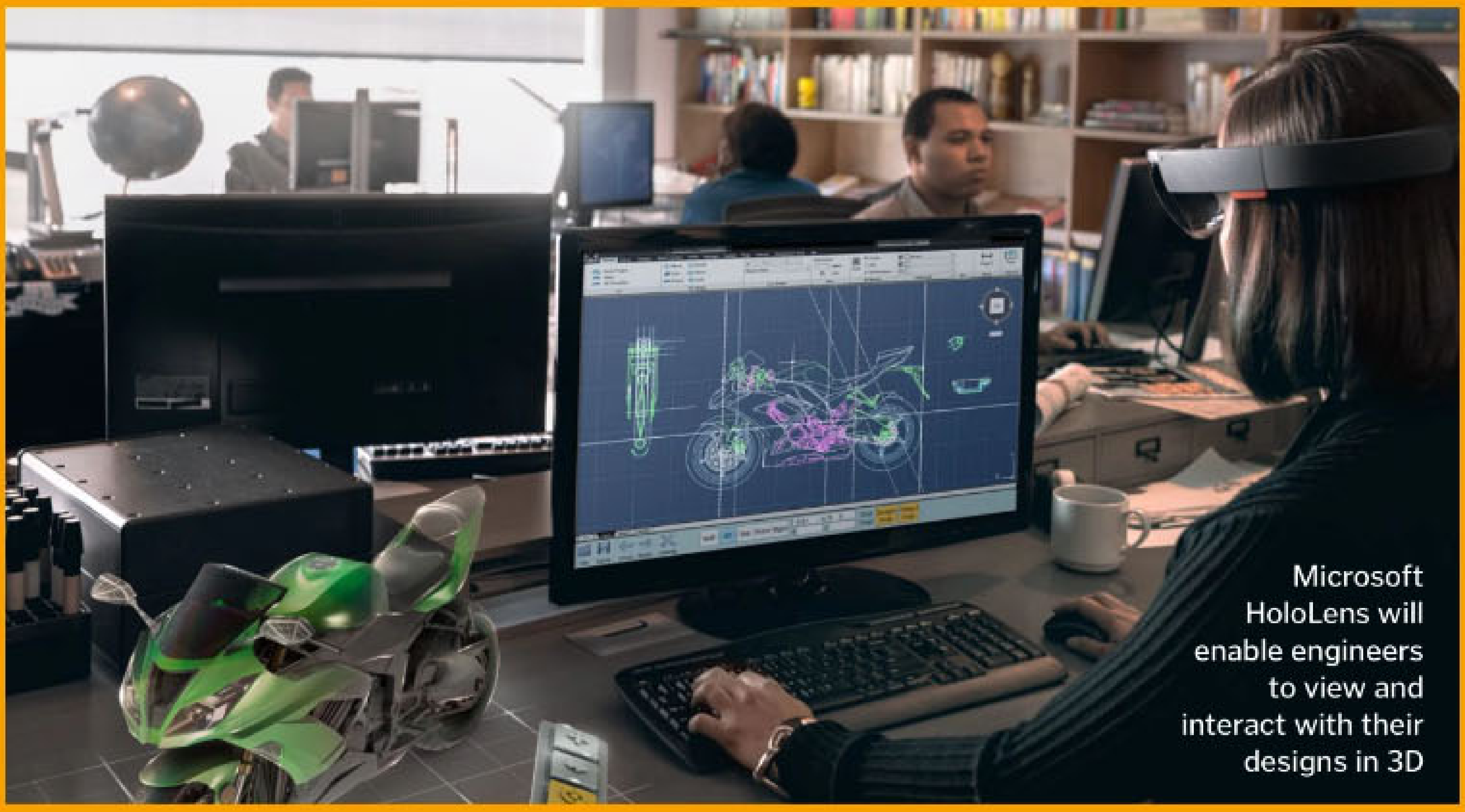
Virtual reality has already become a crucial part of astronaut training, enabling them to practise spacewalks in a virtual environment before doing them for real, and is even being used once they get into space. A Microsoft HoloLens onboard the International Space Station enables ground operators to see through the eyes of the astronauts and provide real-time guidance, as well as project helpful holographic illustrations onto their view. For tasks that astronauts are not able to do themselves, a head-mounted display enables operators on the ground to see through the eyes of NASA's Robonaut instead, which can then mimic its operator's movements to perform tasks just like a human. Virtual reality also makes it possible to explore other planets from the safety of Earth, as NASA scientists can step into images taken by the Curiosity Rover to walk on Mars for the first time.

> "Ground operators can see through the eyes of astronauts and give real-time guidance"

Engineering

Visualising designs in 3D using virtual reality

When designing a new product, it's difficult to get a sense of what the finished item will be like from 2D illustrations. With virtual reality, designers and engineers can use 3D modelling to create virtual prototypes of ideas, and use a head-mounted display to examine them from all angles. For example, car manufacturers can sit inside the design of a new vehicle to make sure it looks and feels right before they build the real thing. Any tweaks can easily be made in the 3D design, rather than creating a new prototype from scratch.

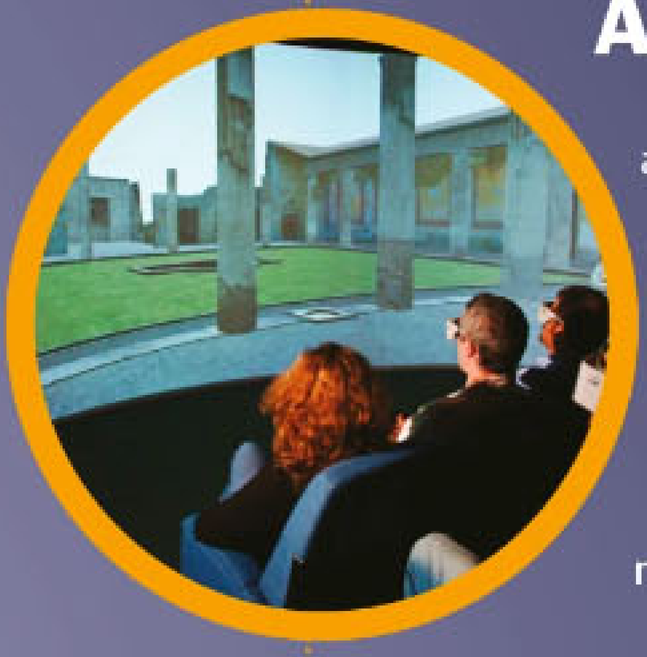


Microsoft HoloLens will enable engineers to view and interact with their designs in 3D

Virtual world

Stereoscopic tech will touch almost every industry

Archaeology



VR headsets enable archaeologists to walk around places as they would have appeared in the past, giving them a better understanding of what life was really like there. They also make it possible to see ancient sites that are otherwise too remote, dangerous or fragile to visit in person.

Crime solving

Based on factual data and photographs, 3D reconstructions of crime scenes can be created and explored using head-mounted displays. This enables investigators and even juries to examine the scene in great detail without contaminating any evidence, helping them to deduce what may have happened.

Sport

As well as creating a more immersive way to watch sporting events at home, virtual reality can also be used to improve the athletes' performance. While training in a virtual simulation, their body movements can be monitored in real-time, providing useful feedback to improve their game and help them avoid injury.

Tourism

Before you book your next holiday, your travel agent may be able to give you a taster of your destination using virtual reality. Popping on a headset will transport you to far away places, and even let you visit locations it's not possible, or too expensive, to travel to in real life.

© SPL; Alamy

FUTURE OF FOOD

Why you'll be eating lab-grown burgers, 3D-printed pizzas & insects

In the year 2050, dining at your favourite restaurant is likely to be an altogether different experience. After being greeted by your robot waiter and taken to your table on a hoverboard, you will be left to peruse the holographic menu at your leisure. As you scroll through the options, you'll notice that all of the usual dishes are still there, but with a few unusual twists thrown in.

For your starter, you'll tuck into a delicious Caesar salad containing protein-rich mealworms instead of chicken, and sprinkled with crunchy croutons made using cricket flour.

Creepy-crawly protein
Munching on mealworms and crickets is a healthier and more environmentally friendly alternative to eating beef or chicken.

3D-printed meals
Preparing your dinner is about to get a whole lot easier thanks to the 3D printed food revolution.

Lab-grown meat
No animals need to be harmed in the making of your favourite meals, as scientists can grow meat from cells.

Genetically modified veg
Fruit and veggies can be tweaked to make them easier to grow, and more nutritious and tastier too.

DID YOU KNOW? *Producing 500g (1lb) of beef uses 2,000 times as much water as producing the same amount of cricket meat*

Next, your android waiter 2.0 will bring over the mouth-watering main course; a meaty burger that has been grown in a Petri dish, garnished with crisp lettuce freshly picked from an underground farm and juicy tomato that has been genetically modified to contain extra vitamins. Then, if you still have room for dessert, you'll be able to choose from a range of sweet treats that have been designed on a computer and printed directly onto the plate.

These unconventional dishes may seem bizarre and perhaps stomach-churning to us now, but in the future they could help to solve a global food crisis. Over the next 35 years, the world's population is expected to exceed nine billion, meaning an extra two billion hungry mouths to feed. To fulfil this demand, the amount of food we grow will need to increase by 70 per cent, but with most of the planet's farmland already being used, and billions of its inhabitants already undernourished, this is going to be a major challenge.

Today's global food industry is already unsustainable, with agriculture responsible for almost a third of all human-caused greenhouse gas emissions. From the nitrous oxide given off by crop fertilisers, to the carbon dioxide generated as the produce is transported around the world, these gases are trapping heat in the atmosphere and gradually warming the surface. In turn, the changing climate makes it difficult to grow more crops, and so scientists will need to step in more and more to help. By genetically modifying the plants we grow, not only can the more vulnerable species be made able to withstand harsher, inhospitable environments, but the hardier species that can survive could also be made more nutritious to ensure we all get the vitamins and minerals we need.

Although growing fruit and vegetables generates a great deal of greenhouse gas, it is livestock production that is the biggest contributor to global emissions. It is estimated that producing one 230-gram (half-pound) hamburger generates the same amount of greenhouse gas as driving a typical passenger car for 16 kilometres (ten miles). Among these gasses is methane, which is about 25 times more effective at warming the planet than carbon dioxide. As demand for meat grows, so does the list of negative consequences for our planet, so something needs to be done very soon.

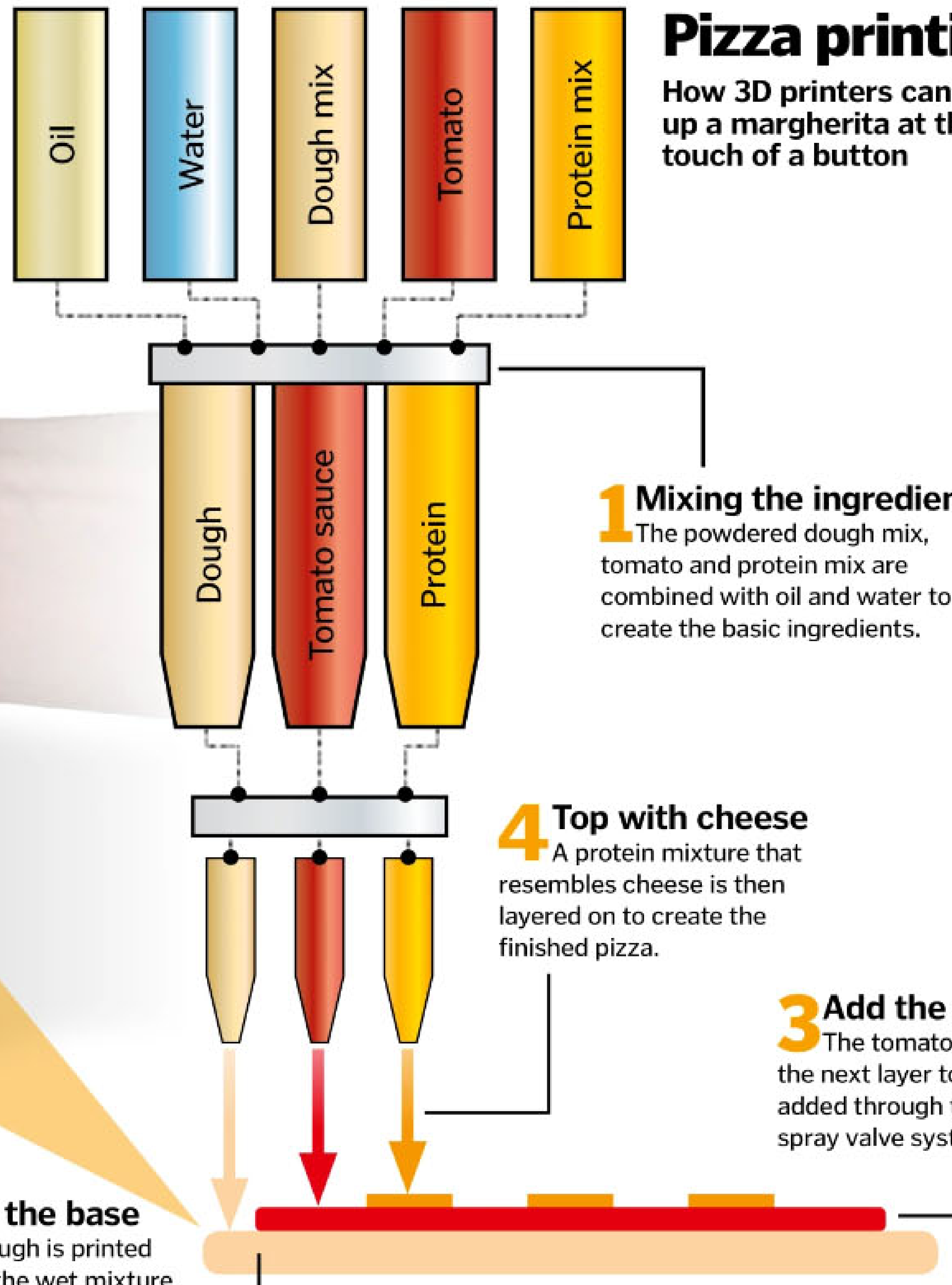
Of course, one simple solution to the problem is to eat less meat, but for a mostly carnivorous global population that gets through around 285 million tons of the stuff each year, this idea is unlikely to catch on. Therefore, tasty alternatives need to be found, and our idea of what we consider to be meat may need to change too. For example, the beef and chicken in your burgers and burritos could soon be swapped for crickets and locusts, or perhaps be grown in a lab instead of on a farm.

In fact, even traditional farms as we know them are likely to look completely different in just a few decades time. Gone will be the days of farmers having to drive tractors and milk the cows themselves, as autonomous machines are already starting to take over and make the industry more efficient.

Once these eco-friendly and sustainable foods have been harvested, we might not recognise the products that hit the shelves. Instead of packets and tins, your local supermarket will sell ingredients in cartridges that you can load into your 3D printer at home. Then, with a press of a button, you can sit back and relax while the machine builds a delicious dish – layer by layer – that is sure to impress your dinner party guests.

Pizza printing

How 3D printers can cook up a margherita at the touch of a button



1 Mixing the ingredients The powdered dough mix, tomato and protein mix are combined with oil and water to create the basic ingredients.

2 Print the base The dough is printed first, with the wet mixture layered directly onto a hot plate and cooked.

3 Add the sauce The tomato sauce is the next layer to be added through the spray valve system.

4 Top with cheese A protein mixture that resembles cheese is then layered on to create the finished pizza.

3D-printed meals

3D printing is already being used to create car parts, clothes and even prosthetics, but next on the agenda is your dinner. You will soon be able to make a meal from scratch simply by choosing a recipe and clicking print. 3D food printers that can produce intricate edible designs from sugar and chocolate already exist, but the Foodini, a 3D printer that can create a wide range of both savoury and sweet foods, is due to go on sale in 2016. Once you select your desired recipe, Foodini will tell you which ingredients to place into its food capsules, then it will start printing your dish in layers until it is ready for you to cook in the oven or pan. It can create crackers, pizzas, veggie burgers and even ravioli, allowing you to keep track of exactly what goes into your meal. As well as benefiting you at home, 3D printing food could also help to improve the quality and variety of meals available for astronauts on long duration space missions. A NASA-funded project has developed a machine that can print a pizza from dried ingredients with a 30-year shelf life, meaning it could someday feature on a menu on Mars.

Beijing Hesion 3D Technology is developing a pancake-printing machine, to satisfy those creative sweet treat cravings

© Corbis; Dreamstime

Lab-grown meat

Discover how scientists can create burgers without harming cows

Global demand for meat is expected to increase by more than two-thirds in the next 40 years, and we are already struggling to cope. Current methods for producing meat are not very sustainable, as huge amounts of land and other resources are needed to rear livestock. As these assets get harder to come by, the price of meat will continue to rise, meaning that it could soon become an unaffordable luxury. The meat industry is also having a negative environmental impact on the planet, with the animals releasing huge amounts of methane, a greenhouse gas that contributes to global warming.

Many scientists believe the solution to this looming problem is cultured meat grown in the lab, and a team from Maastricht University in the Netherlands has already perfected the technique. By extracting stem cells from a living cow they have been able to grow muscle tissue and turn it into a burger that tastes a lot like the real thing. The cells taken from just one cow could produce 175 million burgers, which would normally require meat from 440,000 cows; better still, the animal remains unharmed. It's not just beef that can be grown this way either, as the method can easily be replicated to create chicken, pork and other meats too.

Before you start planning your lab-grown barbecue though, scientists believe it could be another ten to 20 years before the meat becomes commercially available. It currently costs around €250,000 (£185,000 or $280,000) to produce a single burger, but as the method is refined, cultured meat could become cheaper than the conventional kind grown on farms by 2035.

How to build a burger

"Cells taken from just one cow could produce 175 million burgers"

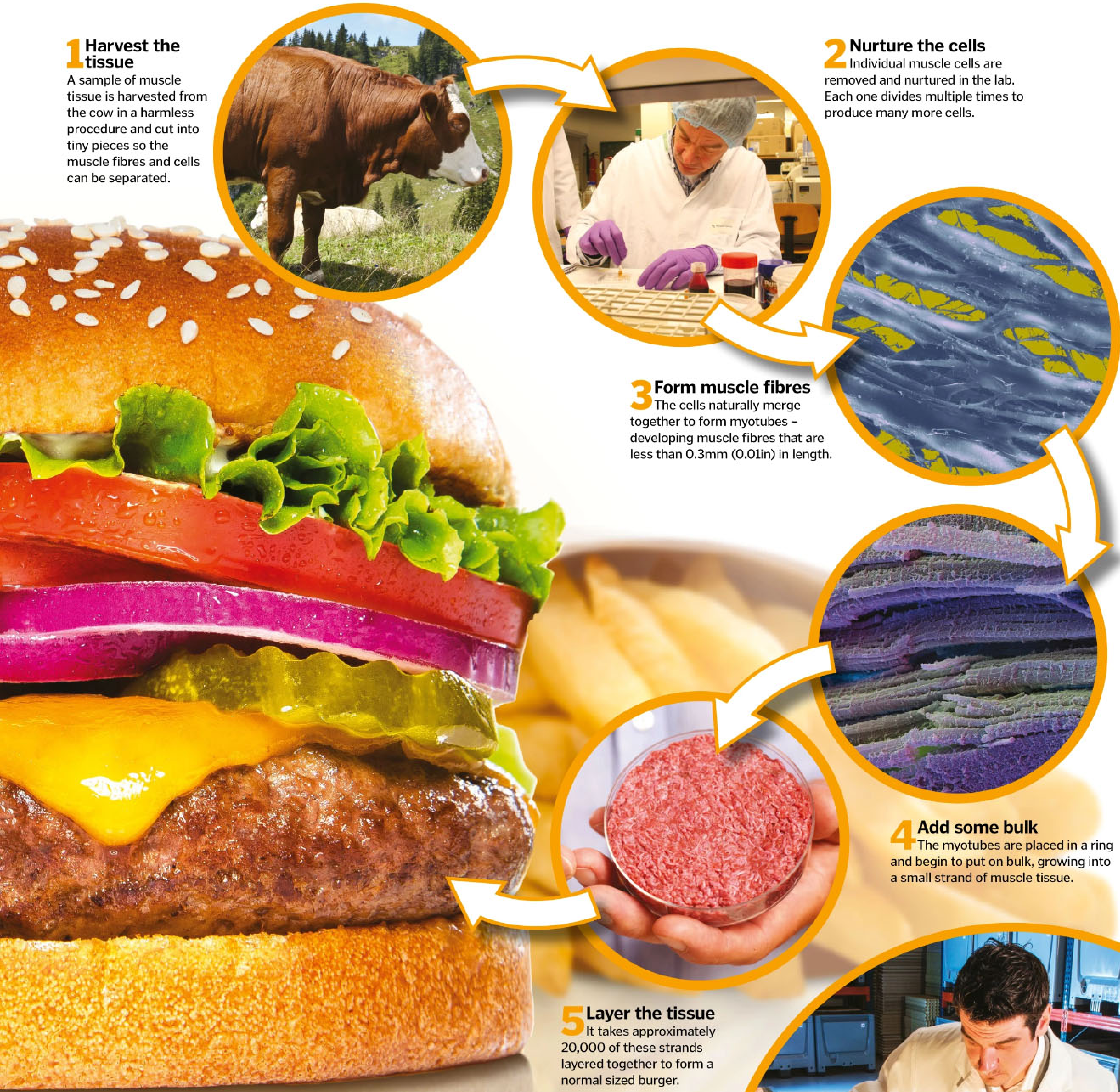
The cheese and meat in an Impossible Burger are made entirely from plants

Turning plants into beef

If a lab-grown burger doesn't get your mouth watering, then maybe one made entirely from plants will. Impossible Foods has discovered a way to make meat and cheese without animals, yet still promise that it will 'delight and nourish the most discerning meat lover'.

From plants such as greens, grains and beans, they extract proteins that have a meaty texture, flavour or aroma. The proteins are then mixed with amino acids, vitamins and fats – also from plants – to create the three main components of meat; muscle, connective tissue and fat. When these are combined in the right proportions, they form a burger that looks, tastes and smells just like ground beef. The Impossible Burgers are already available in four restaurants in the US, and will be followed by a range of other meats and dairy products, all made entirely from plants.

DID YOU KNOW? *Impossible Burgers contain haem, a substance found on bean plant roots that looks and tastes like blood*



1 Harvest the tissue

A sample of muscle tissue is harvested from the cow in a harmless procedure and cut into tiny pieces so the muscle fibres and cells can be separated.

2 Nurture the cells

Individual muscle cells are removed and nurtured in the lab. Each one divides multiple times to produce many more cells.

3 Form muscle fibres

The cells naturally merge together to form myotubes – developing muscle fibres that are less than 0.3mm (0.01in) in length.

4 Add some bulk

The myotubes are placed in a ring and begin to put on bulk, growing into a small strand of muscle tissue.

5 Layer the tissue

It takes approximately 20,000 of these strands layered together to form a normal sized burger.

© Science Photo Library; Corbis; Thinkstock; Dreamstime

The insect diet

People throughout Africa and Asia regularly eat bugs as a source of protein, but these creepy crawly snacks could soon catch on in the Western world, too. The United Nations' Food and Agriculture Organization has suggested that insects are a healthier, more environmentally friendly and more sustainable alternative to conventional meat, and insect farms are already popping up across the world.

Although they might not seem appetising, many insects are very nutritious, containing lots of good fats, calcium, iron and zinc. Rearing them also requires much less land than traditional meat production and results in considerably fewer greenhouse gas emissions.

As they are cold-blooded, insects are much more efficient at converting food into protein, with cows needing 12 times as much food as crickets to produce the same amount of protein. They can also be fed on food scraps and animal manure to help recycle waste.

The Micronutris insect farm in France breeds many species of insect for human consumption

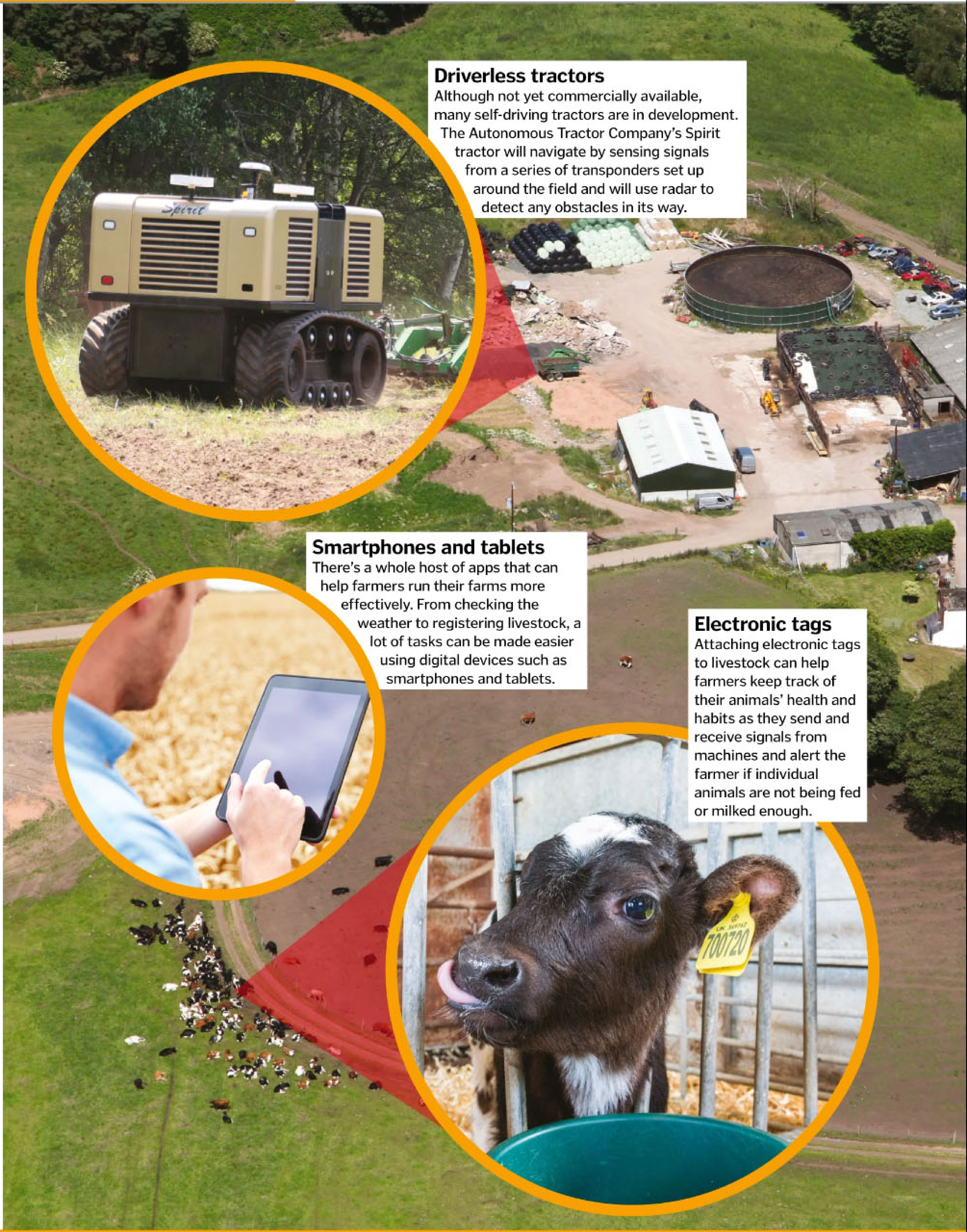
Farms of tomorrow

How technology will help farmers cope with increasing demand

With more and more mouths to feed, farms need to be run as efficiently as possible in order to keep up with demand. As a result, many farmers are turning to new technologies for help, using precision systems to make many of their day-to-day tasks easier.

For example, GPS is already widely used to ensure tractors are driven in straight lines across fields, preventing them from overlapping their routes. This helps to save fuel, fertiliser and seed that would otherwise be wasted as the farmer covers the same piece of land again and again. However, in the not-so-distant future, farmers may not need to drive their tractors at all, with several self-driving machines currently in development. Other farming machinery is also becoming increasingly hi-tech, with robots being used to feed and milk livestock more efficiently.

Although some of this cutting-edge tech is unaffordable for many farmers at the moment, the farms of the future are likely to be incredibly large-scale businesses, which need to be almost entirely automated in order to be cost-effective. So instead of mucking out the pigs and feeding the cows, future farmers will be able to sit back and let the machines do all the hard work, while they control everything from their smartphone or tablet.



Driverless tractors
Although not yet commercially available, many self-driving tractors are in development. The Autonomous Tractor Company's Spirit tractor will navigate by sensing signals from a series of transponders set up around the field and will use radar to detect any obstacles in its way.

Smartphones and tablets
There's a whole host of apps that can help farmers run their farms more effectively. From checking the weather to registering livestock, a lot of tasks can be made easier using digital devices such as smartphones and tablets.

Electronic tags
Attaching electronic tags to livestock can help farmers keep track of their animals' health and habits as they send and receive signals from machines and alert the farmer if individual animals are not being fed or milked enough.

Going underground

An abandoned World War II bomb shelter may seem like an unusual location for growing vegetables and herbs, but subterranean farms could be the future of crop growing. With conventional farmland becoming more and more scarce, and crops at risk from changing weather, indoor alternatives can be used to fulfil the demand and provide a more controllable growing environment. To grow plants indoors, hydroponic systems can be used. Instead of soil, the plants sit in trays of water enriched with nutrients, while banks of LEDs overhead provide light for energy.

The Growing Underground farm 30 metres (100 feet) beneath the streets of London uses a controlled hydroponics system to grow crops all year round, and can deliver its produce to the city's restaurants and wholesalers within just four hours of being harvested. As only green energy is used to power the lights, the farm is also carbon-neutral.

Growing Underground has turned an abandoned bomb shelter into a sustainable farm

DID YOU KNOW? *Most of the sugar beet, corn and soybean crops growing in the US have been genetically engineered*

> "GPS is already widely used to ensure tractors are driven in straight lines"

Automated milking machines

Robot milking machines allow cows to be milked whenever they want, so the farmer doesn't have to herd them up at 5am. The machine knows which cow is which and automatically attaches the milking teats when they enter the booth.

Robot livestock feeders

Automated feed pushers can sweep the livestock's feed towards them when they are lined up at the feed fence, ensuring that they have a constant supply of food and giving the farmer one less back-breaking task to do.

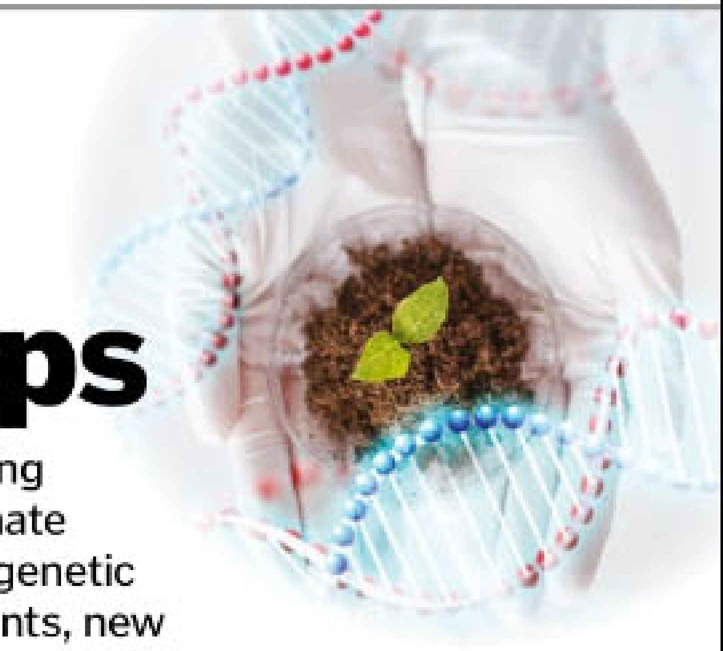
Aerial drones

Drones can be used to produce accurate maps of farmland to calculate fertiliser needs, give farmers a bird's eye view of their land to help them monitor crops and even scare away pests before they can damage the yield.

Farm management software

Tech-savvy farmers can manage many aspects of their farm from their computer, using software to map their land, calculate the resources they need and monitor their livestock. This can help decrease wastage and boost productivity, making the business more profitable.

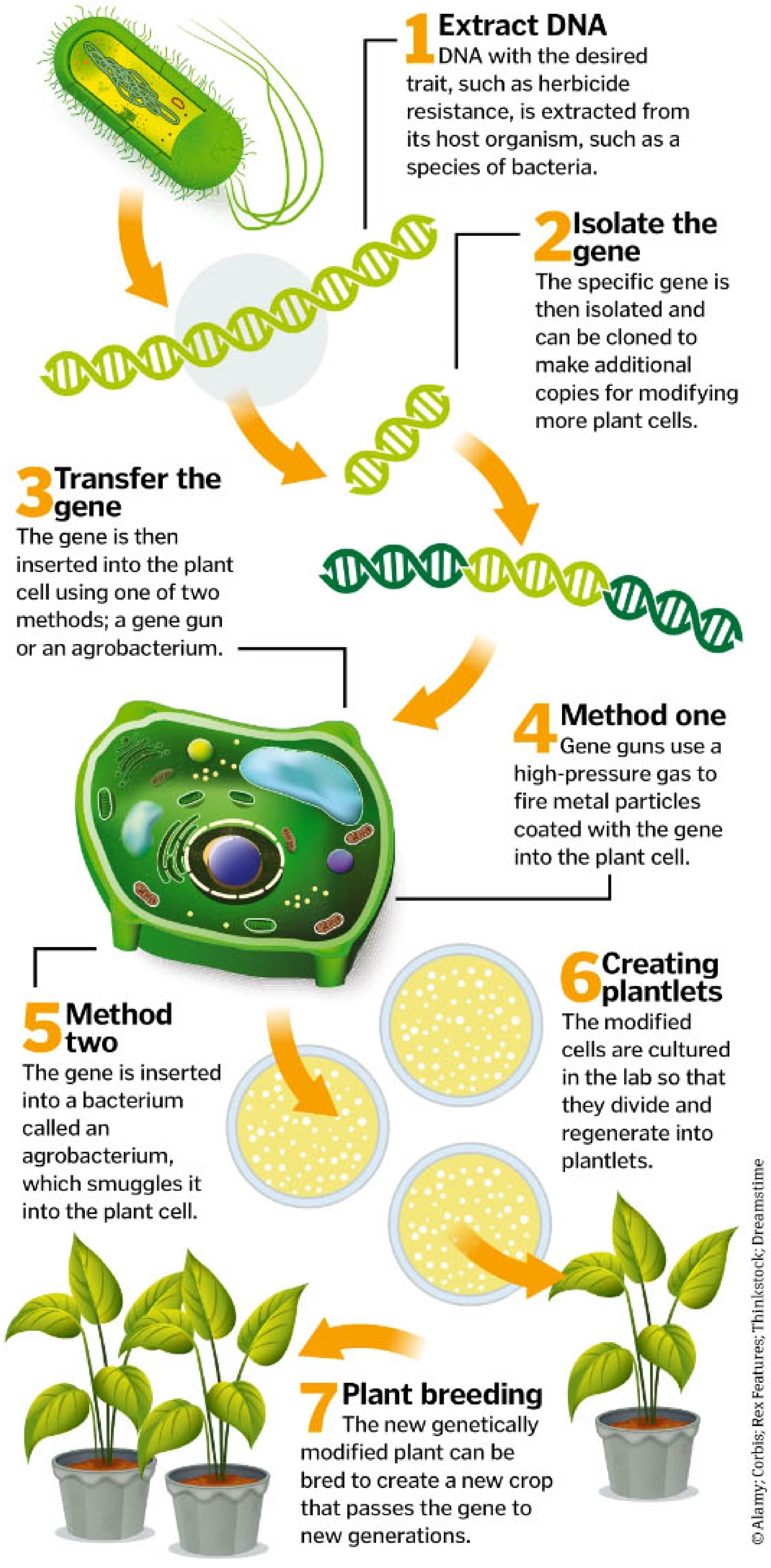
Genetically modified crops



Growing enough food for the rapidly growing population of a planet with a changing climate would be more or less impossible without genetic engineering. By modifying the genes of plants, new crops can be created that are resistant to weed-killing herbicides and disease-causing pests, or are able to grow in inhospitable conditions. These genetically modified organisms (GMOs) can also be created to produce fruit and vegetables that stay ripe for longer, reducing wastage, or even contain more of the vitamins we need to stay healthy. Although there is some controversy surrounding GMOs, there is currently no evidence that they are bad for your health; people and livestock have been consuming them for decades with no ill effects.

How to genetically modify a plant

The simple steps for creating a modified food crop



1 Extract DNA
DNA with the desired trait, such as herbicide resistance, is extracted from its host organism, such as a species of bacteria.

2 Isolate the gene
The specific gene is then isolated and can be cloned to make additional copies for modifying more plant cells.

3 Transfer the gene
The gene is then inserted into the plant cell using one of two methods; a gene gun or an agrobacterium.

4 Method one
Gene guns use a high-pressure gas to fire metal particles coated with the gene into the plant cell.

5 Method two
The gene is inserted into a bacterium called an agrobacterium, which smuggles it into the plant cell.

6 Creating plantlets
The modified cells are cultured in the lab so that they divide and regenerate into plantlets.

7 Plant breeding
The new genetically modified plant can be bred to create a new crop that passes the gene to new generations.

© Alamy; Corbis; Rex Features; Thinkstock; Dreamstime

THE FUTURE OF CINEMA

How the movie industry is poised to fight declining sales with virtual reality tech & more

Over the last century, the film industry has grown exponentially from its humble beginnings, expanding across the globe to upward of 135,000 movie screens, and become an integral part of modern culture. But behind the scenes, all is not well. Anguished industry leaders are wringing their hands over a worrying new trend: people aren't going to the movies as much as they used to.

Box office revenues fell by five per cent between 2013 and 2014 in North America – declines that meant some of the country's premier cinema chains' profits plummeted by more than 50 per cent. The Motion Picture Association of America found that between 2012 and 2013, the number of 18-to-24-year-olds classed as 'frequent moviegoers' fell by 17 per cent, with the 12-to-17 age bracket dropping by 13 per cent. These groups have traditionally been relied upon to come through the doors week after week and empty their wallets over films and snacks.

For today's teenagers, the allure of the silver screen is just not what it was for their parents and grandparents. Gone are the days when the whole community would descend on the picturehouse of a Friday evening, eager to catch the latest release.

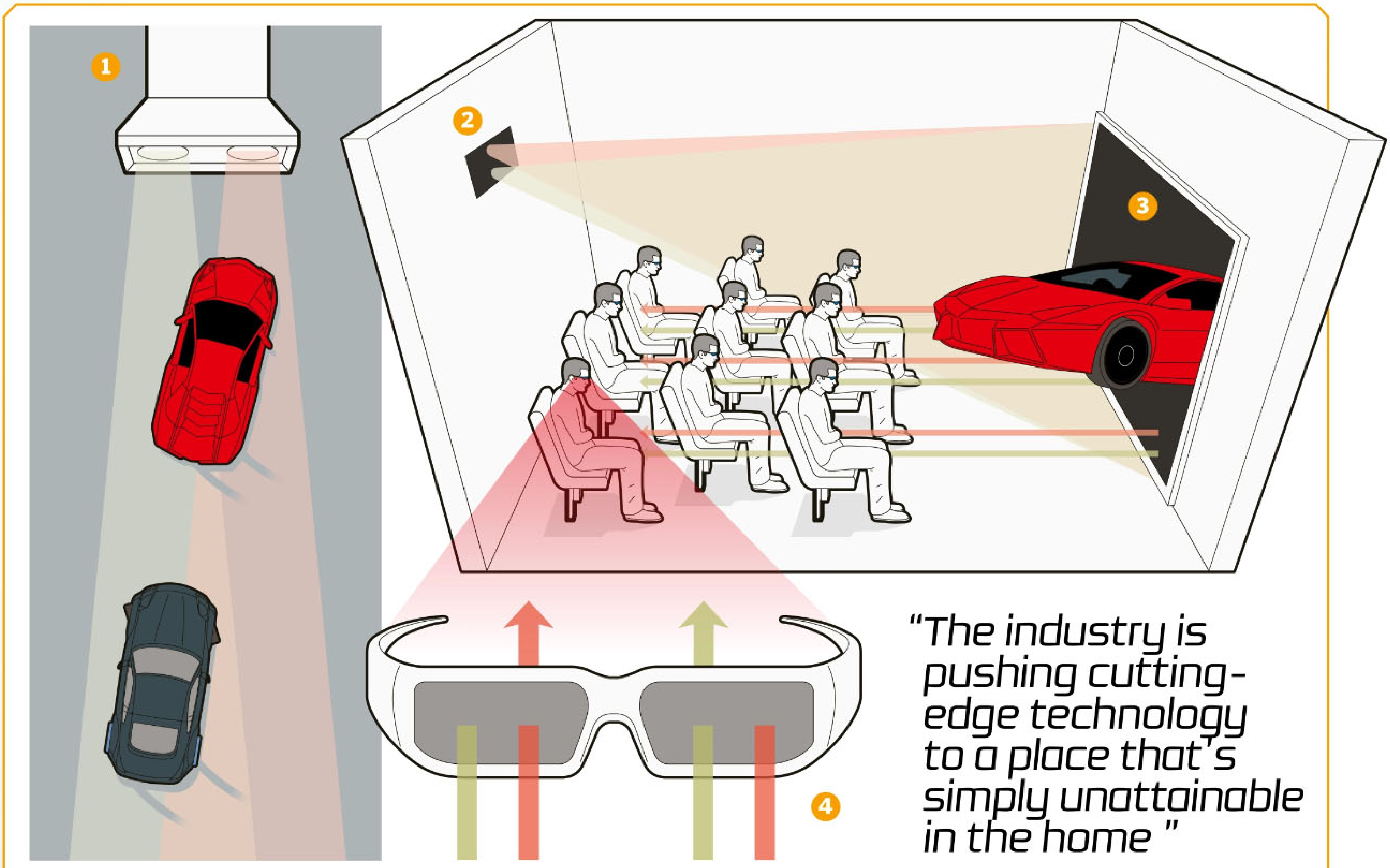
The ubiquity of smartphones, tablets and laptops, along with the proliferation of on-demand screening services, mean the next movie is seldom more than a couple of clicks away. In rich countries, families have the means to create convincingly cinematic experiences in the comfort of their own homes with huge flatscreens and surround sound systems.

But like any good action hero, the motion-picture industry is fighting back. On multiple fronts, creators are pushing cutting-edge cinema technology to a place that's simply unattainable in the home, to add extra facets to the movie-going experience and motivate people to leave the house and head for the movie theatre.

One obvious tack is: bigger and better. Covering the bigger angle is IMAX – cinemas with giant, immersive, field-filling screens that swallow audiences into the action. After the technology was debuted during the 1970 world's fair, IMAX went public in 1994 and began its romance with Hollywood, pioneering a way to digitally remaster film for its humongous curved screens. Today, there are over 800 IMAX screens across the globe, many housed within traditional cinema multiplexes, and they're as popular as ever.

As for "better", the laser-projection revolution is now upon us. For almost 100 years, film projectors

DID YOU KNOW? *An IMAX projector weighs over 1,800kg (3,970lb) – the equivalent of a family car!*



> "The industry is pushing cutting-edge technology to a place that's simply unattainable in the home"

How RealD 3D works

RealD is the most widely used technology for watching 3D films at the cinema

1 Stereoscopic capture The brain perceives depth and distance by merging images from each eye. In 3D filmmaking, special cameras capture two side-by-side images to simulate the perspectives of a viewer's left and right eye.

2 Sequential projection Left and right eye images are beamed sequentially at a rate of 144 frames per second through a single digital projector, with each passing through a circularly polarising light filter of opposite handedness.

3 Silver screen A special screen embedded with silver (or other metallic) dust perfectly maintains the polarisation of each image when it reflects the projected light back toward the audience.

4 Special specs RealD glasses are fitted with a pair of oppositely handed circular polarisation filters, which allow each eye to view only its intended frames. This creates the impression of depth in the picture.

have used electric-arc lamps – first carbon, then xenon – as their light sources. In a traditional film projector, light passes through the 35-millimetre film and a magnifying lens to project the image onto the screen. Over the last decade or so, more and more cinemas have been switching to digital projectors as a way to cut costs and improve picture quality at the same time.

Digital projectors continue to use xenon arc lamps, but a series of prisms and filters splits it into its constituent colours – red, blue and green – and directs each at one of a trio of spatial light modulator (SLM) chips. These measure just a few centimetres across, but split the light into millions of tiny beams, one for each pixel in the frame, according to the digital movie file, before it passes through the projector optics.

The digital setup slashes distribution costs – hard drives are much easier to ship than bulky reels of film – and enables a pristine image to be projected over and over again without ever scratching or losing clarity. Today, over 80 per cent of the world's cinemas have converted to digital, but some film aficionados complain the format loses 35-millimetre film's rich contrasts between light and shadow.

Enter laser projectors. The new kid on the block – which made its commercial debut in 2012 – might finally be the holy grail of film projection. It works just like a digital projector, but uses individual red, blue and green laser light sources in place of the xenon lamp. Its pictures have unparalleled sharpness and superior colour range; finally something to rival the vibrancy and beauty of high-quality film stock. Not only that, but laser projectors also produce images about twice as bright as bulb projectors and are extremely efficient, potentially lasting for ten years in commercial use – a gigantic improvement on the operating life of a xenon bulb, which is typically between 500 and 2,000 hours.

Of course, improvements in lumens and contrasts may be all well and good for film connoisseurs, but they're unlikely to tempt the average 15-year-old through the door. To snare them, cinemas are looking to augment the experience of going to a film. Emerging 4D cinemas offer interactive encounters that blur the line between cinema and amusement park; 3D film technology is much improved, and ambitious studios like DreamWorks are even seriously pursuing futuristic plans to marry virtual reality with film.

The next five years are set to see the swiftest and most significant technological advances in the history of motion pictures, coming soon to a cinema near you!

© Thinkstock

How virtual reality will transform cinema

Step into your own private movie theatre, or even into the movie itself!

DreamWorks – the production company responsible for animation blockbusters like *Kung Fu Panda*, *Madagascar* and *How To Train Your Dragon* – is developing technology that will take audiences right into the heart of its fantastical worlds. Its innovative new format – dubbed 'Super Cinema' – expands the film frame from its current limited screen dimensions into a fully immersive 360-degree swathe, with the viewer at the centre. The idea is that when this is combined with virtual reality (VR) headsets such as Oculus Rift or Gear VR – special goggles that allow wearers to see simulated 3D worlds – viewers will be able to turn their gaze in any direction, to whichever part of the scene captures their attention.

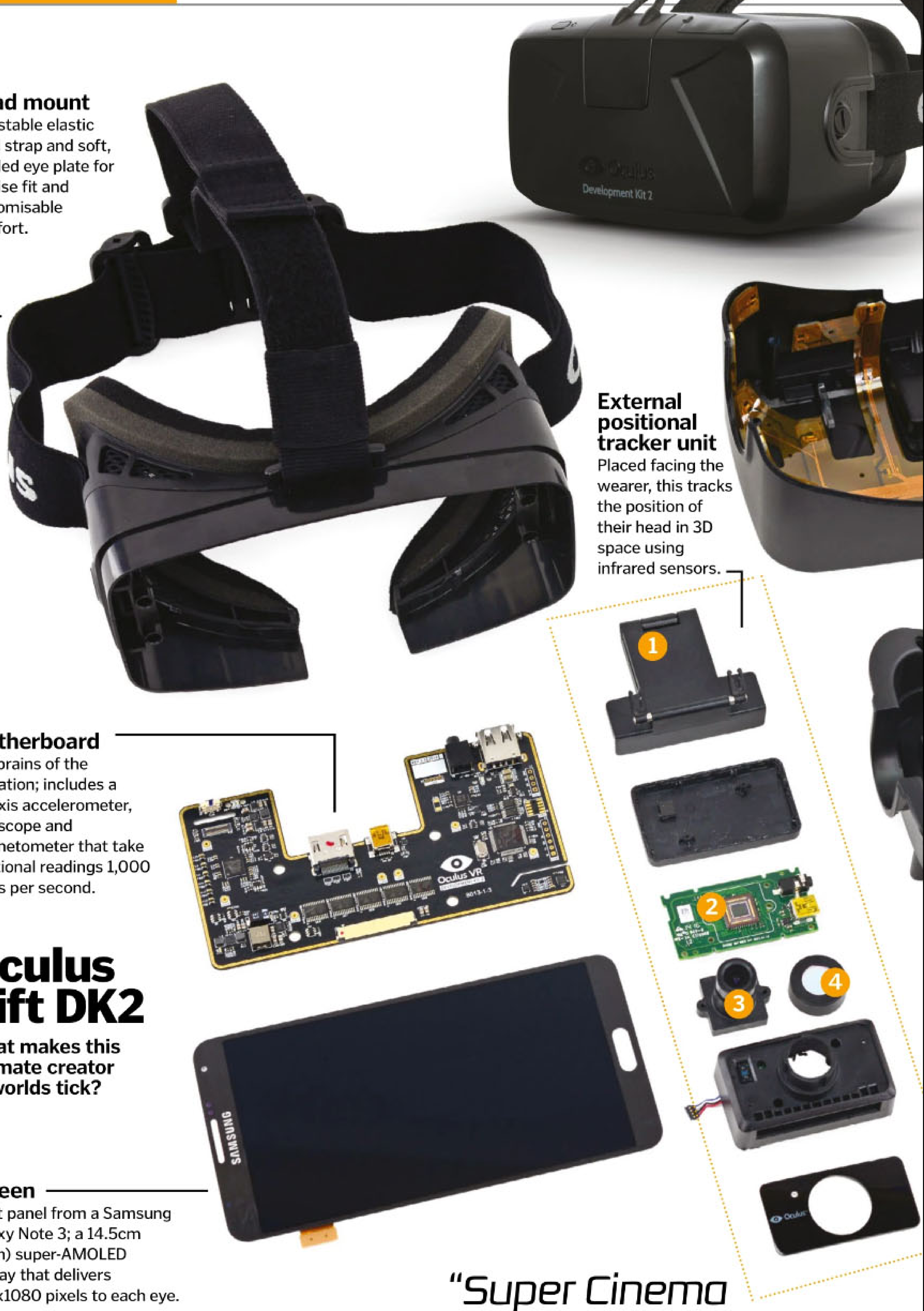
Computer graphics are created by one of two means – real-time rendering or pre-rendering. Real-time rendering is used heavily in other interactive experiences like videogames; the game decides which frame to draw depending on which way the player looks. Unfortunately, this is a time-consuming process, and with graphics as complex as today's CGI animations, this method would slow the frame rate to the point where the viewer start to see the still images switching or the film stalling altogether. Pre-rendering – where each possible view is already drawn and ready to load – makes the process significantly faster and the quality of the experience much smoother.

There are some downsides, though. Each 360-degree film would need to include all possible views of each frame, bumping up file sizes and production times astronomically. Super Cinema would also lack positional tracking – the ability to make minor geometrical adjustments to the image depending on how a person tilts their head – and wouldn't account for person-to-person variations in interpupillary distance (the distance between the eyes), which could make the film disorienting for some viewers.

Key to the success of Super Cinema will be a quality virtual-reality headset. Very few are actually available to consumers just yet, but the market looks set to be flooded with offerings in the next couple of years. Top of every technophile's wish list is the Oculus Rift, whose creators are also pursuing the idea of VR cinema, albeit a little differently. The most recent developer version of the headset runs a 'game' that allows wearers to recreate the moviegoing experience – including picking seats, looking around the theatre and watching the film on a huge screen in a choice of 2D and 3D – wherever the headset is worn – at home, on the bus or in class...

Oculus Rift DK2

What makes this ultimate creator of worlds tick?



Head mount
Adjustable elastic head strap and soft, padded eye plate for precise fit and customisable comfort.

External positional tracker unit
Placed facing the wearer, this tracks the position of their head in 3D space using infrared sensors.

Motherboard
The brains of the operation; includes a six-axis accelerometer, gyroscope and magnetometer that take positional readings 1,000 times per second.

Screen
Front panel from a Samsung Galaxy Note 3; a 14.5cm (5.7in) super-AMOLED display that delivers 960x1080 pixels to each eye.

> "Super Cinema expands the film frame into a fully immersive 360° swath"

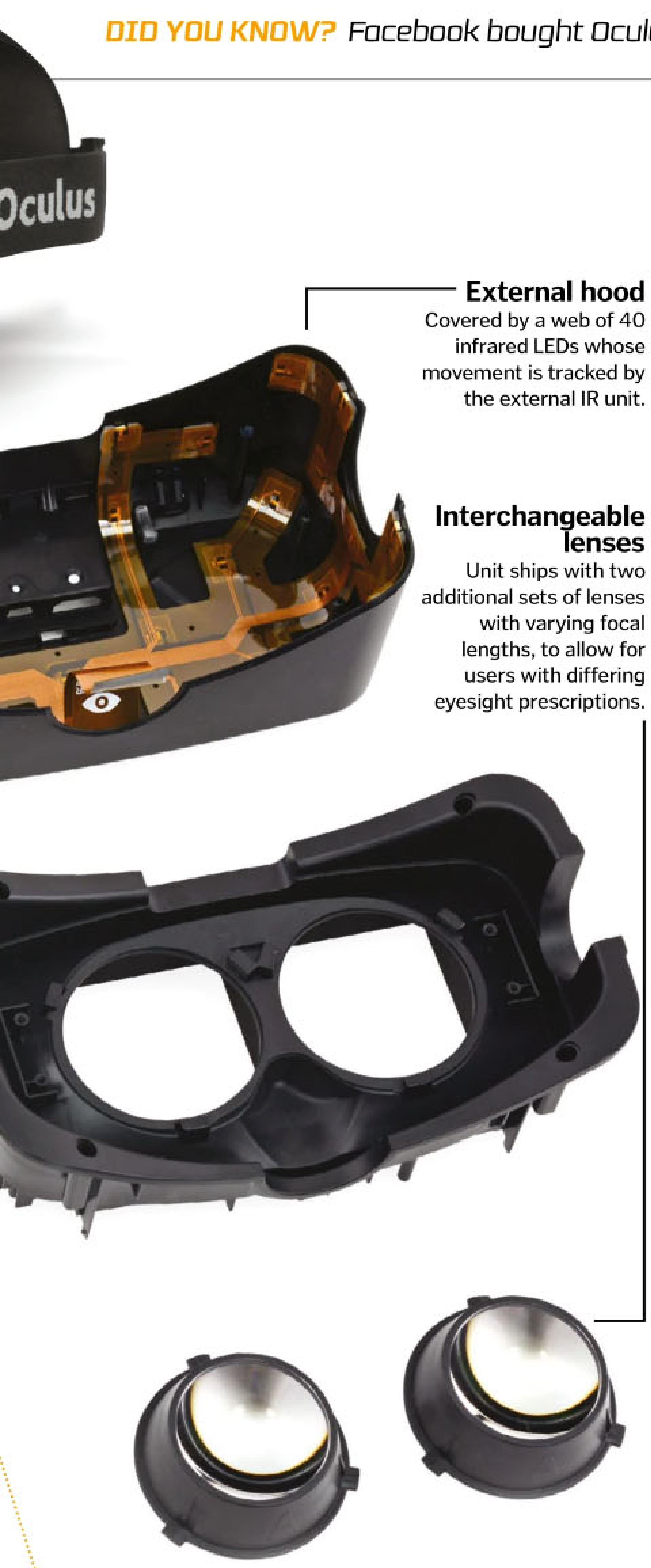
1 Tracker stand
Articulated with several joints in order to get the perfect angle on the headset wearer.

2 Tracker control board
Includes a CMOS image sensor, crystal oscillator and webcam controller.

3 Lens assembly
Fitted with a wide-angle lens that allows the camera to see as much as possible of the headset wearer at any time.

4 Infrared filter
Allows only infrared light to enter into the camera.

DID YOU KNOW? *Facebook bought Oculus in 2014 for £1.3bn ($2bn), aiming to bring it to medicine, education and communication*



External hood
Covered by a web of 40 infrared LEDs whose movement is tracked by the external IR unit.

Interchangeable lenses
Unit ships with two additional sets of lenses with varying focal lengths, to allow for users with differing eyesight prescriptions.

Beyond 3D:

Introducing the fourth dimension

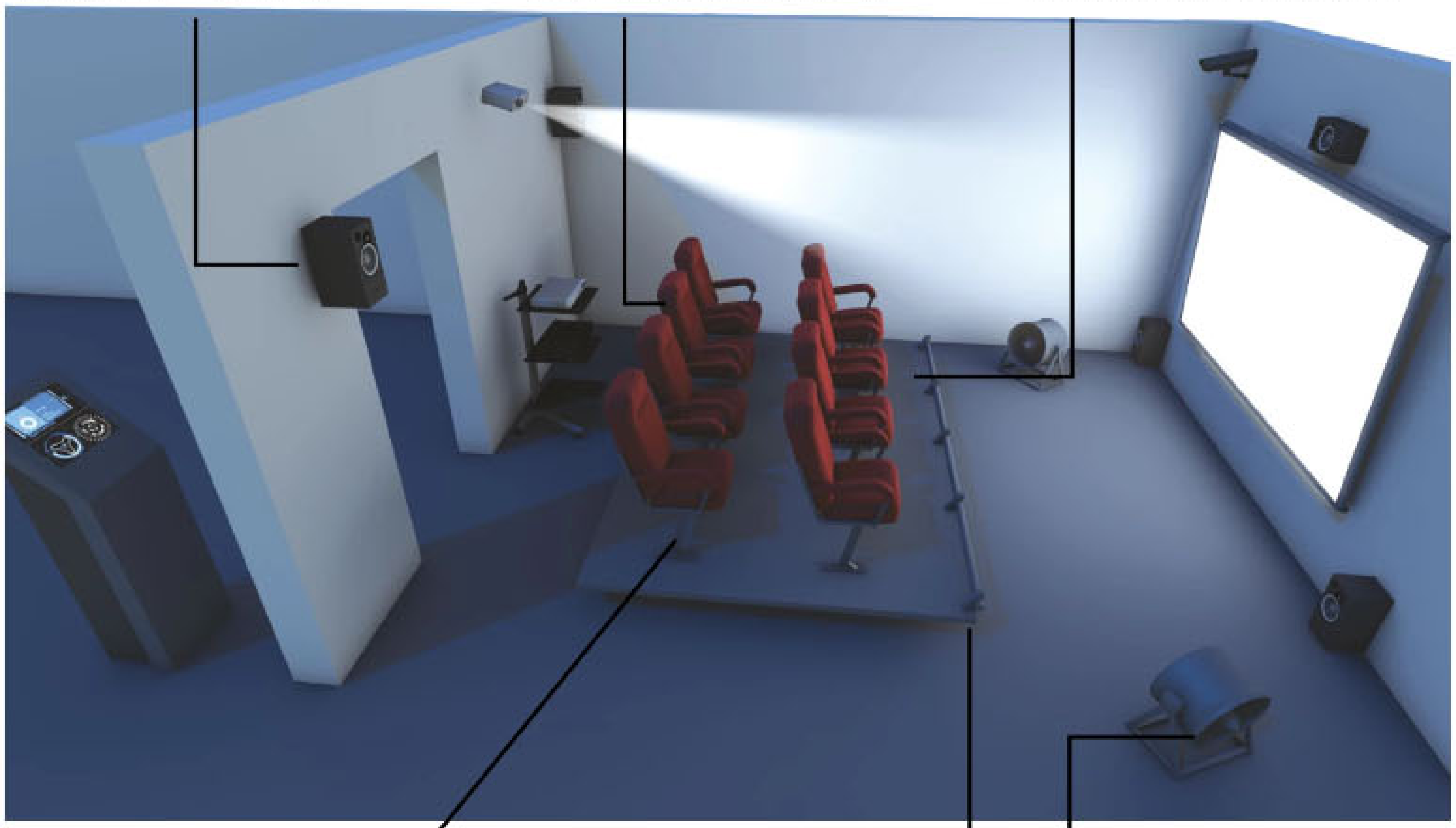
For those eager to feel even closer to the action, 4D cinemas combine the visual richness of 3D film with physical and tactile sensations – flashing lights, air jets, water sprays, scents, smoke, chair movements and more – that sync with and enhance the on-screen drama.

Seats are grouped in small clusters and a large air compressor located behind the auditorium drives their movements, which are pre-programmed, along with other effects, for each film. Some theatres are even touting experiences labelled '5D', '6D' and up, but unfortunately, that's little more than a marketing ploy – with each individual physical effect added to the screening being classed as its own extra 'dimension'.

Sound system
Standard 5.1 surround sound speaker system, augmented by ceiling speakers to offer directional "voice of god" moments.

Vibrating pads
Produce tactile sensations to heighten the drama – for example, a deep rumbling to accompany an avalanche beginning to roll.

Moveable racks
Can move chairs up and down, side to side and tip forward, backward and sideways to mirror the on-screen action.



Tickle stick
Activated by air jets in the chairs – designed to make audiences jump out of their skins during spider scenes!

Hall effects
Includes bubbles, mist, aromas, strobe lighting, and even fire!

Effects jets
Water and air jets intensify scenes with wind, rain, blood and guts, or speed.

How frame rate affects perception

When we watch a film, what our eyes actually see is a stream of still photographs switched so fast through the projector that our brain perceives them as one seamless motion picture, a bit like a hi-tech flipbook.

The threshold below which the brain is able to start perceiving individual images is 16 frames per second (fps), and the higher the frame rate, the more real the reel appears. With this in mind, the film industry grew up around a frame rate of 24fps as a way to balance production costs with painting reality convincingly on screen.

Today, big studios can afford to film movies at higher rates, ostensibly to offer their audiences a greater sense of immersion. But it turns out this can backfire. Peter Jackson's *The Hobbit* (2012) was filmed at 48fps and many people complained. After decades of conditioning, we've become accustomed to 24fps as an integral part of the 'cinematic' feeling, so audiences find hyperrealism disorienting, and a barrier to getting lost in the movie experience.

© iFixit; Pictorial Press Ltd / Alamy

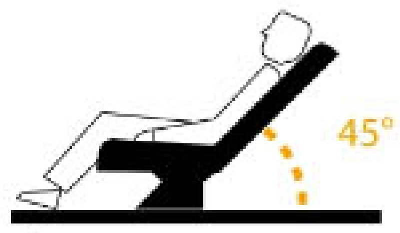
Inside IMAX

Watching an IMAX movie is without question one of the most arresting film experiences in the world. Invented in Canada in 1970, by the end of 2013 there were 837 IMAX theatres in 57 countries across the world. Its defining feature is humongous screens – so large that the images completely fill the viewer's field of vision, giving them a feeling of immersion so strong that some even feel motion sickness during especially dynamic scenes!

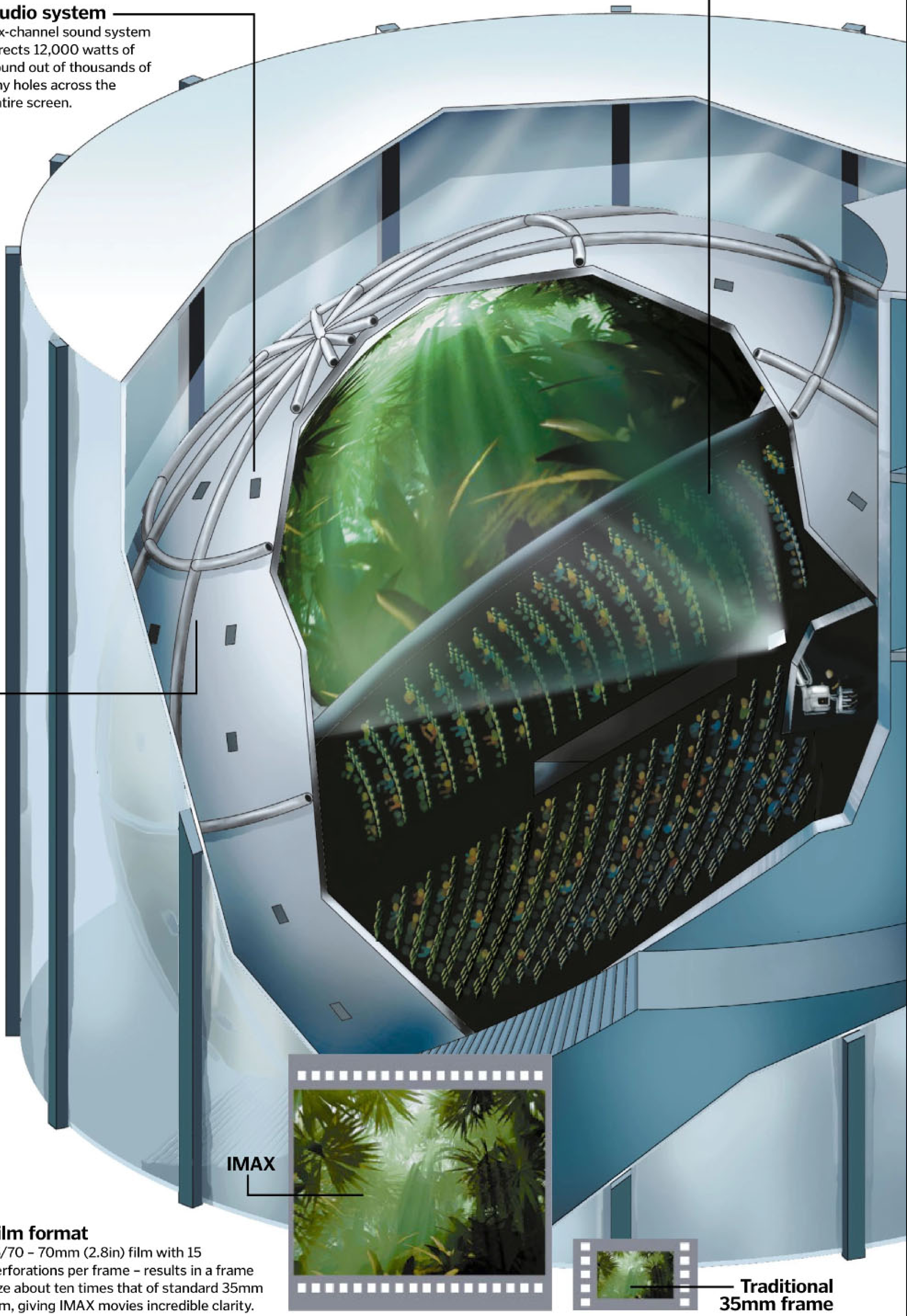
IMAX technology

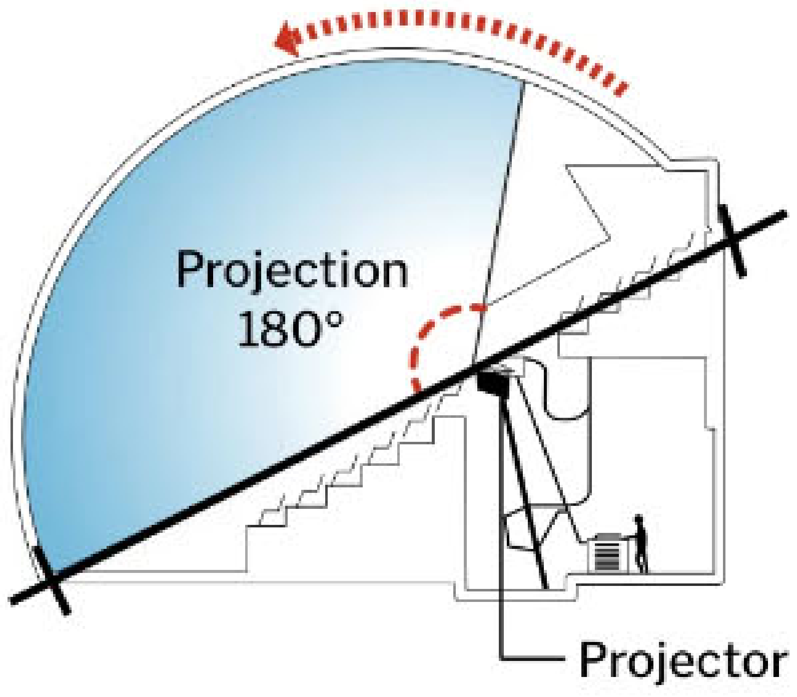
IMAX cinemas display gigantic images with incredible resolution, for a completely immersive experience

Audio system
Six-channel sound system directs 12,000 watts of sound out of thousands of tiny holes across the entire screen.

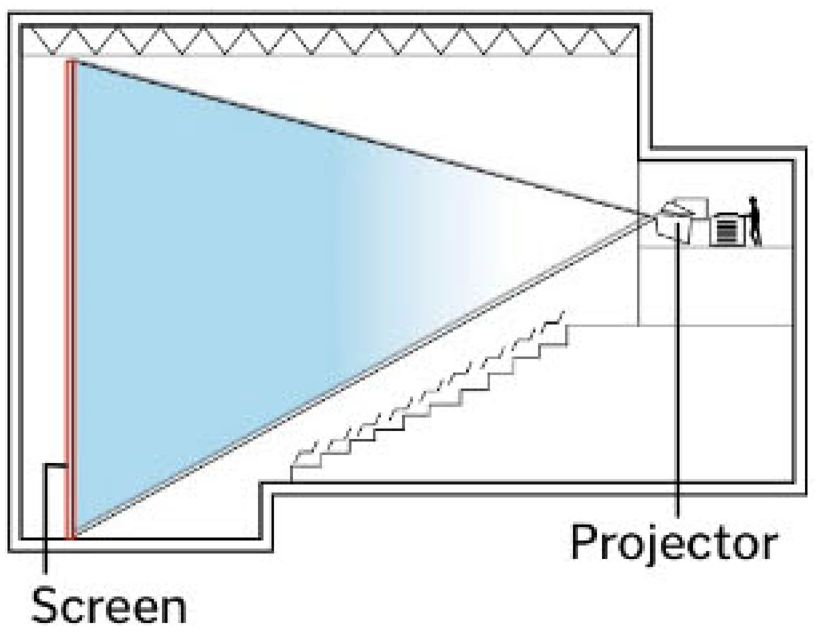


Seating
Steeply racked so that even children's views are unobstructed, and people can gaze up and down as in real life.

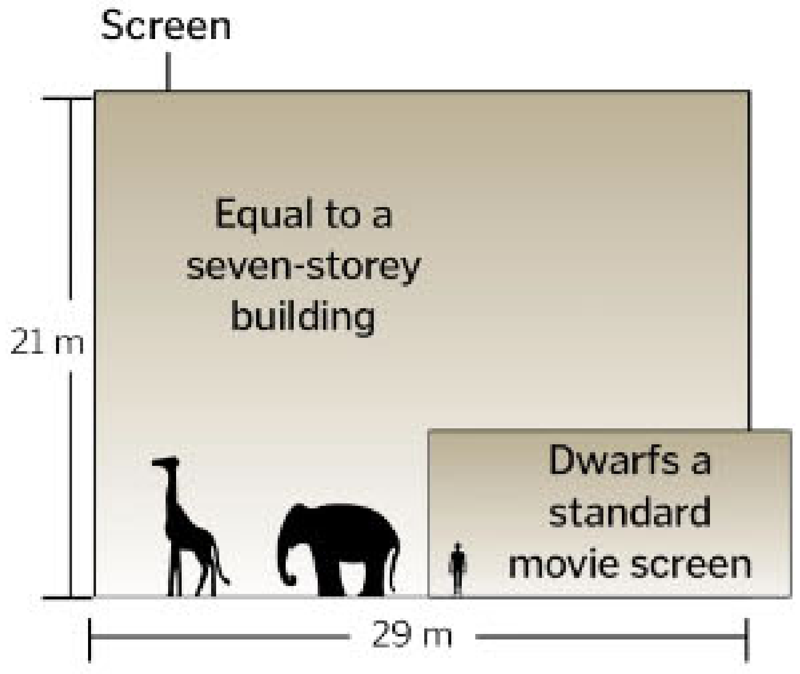




OMNIMAX dome
Hemispherical dome made of metal and coated with highly reflective white paint wraps the entire audience in larger-than-life images.



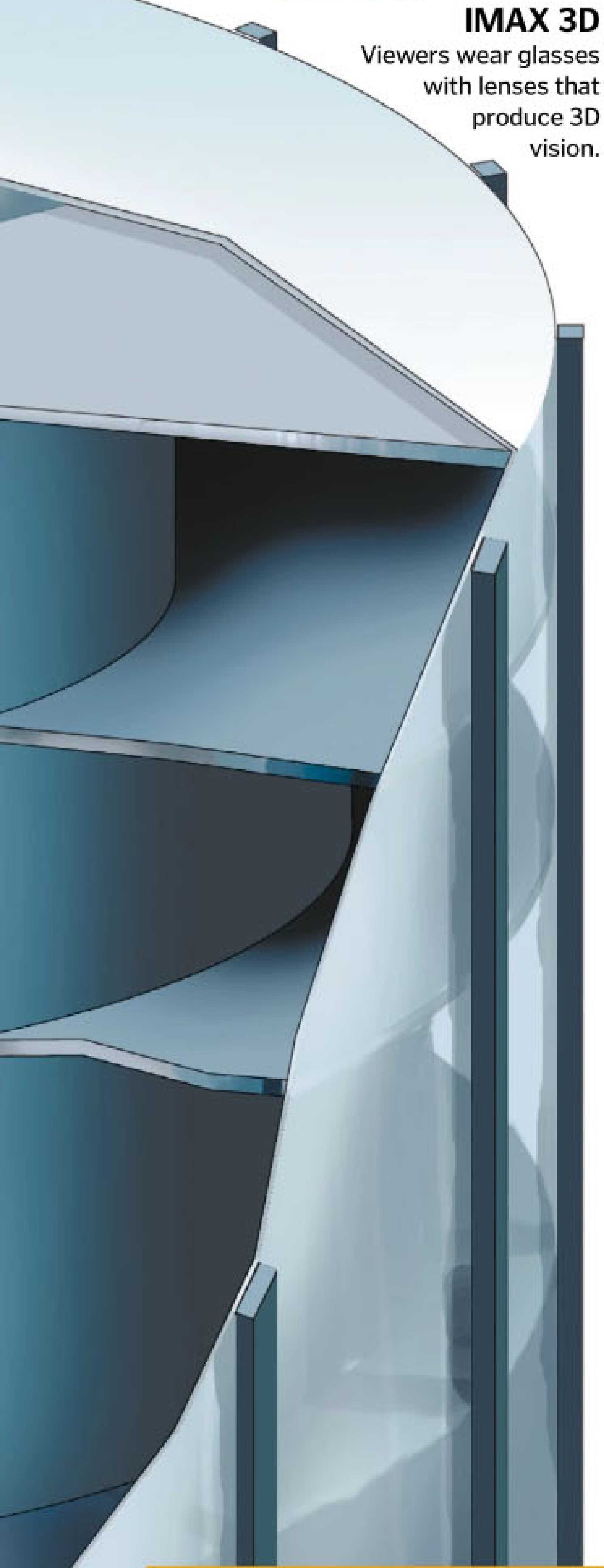
Flat IMAX
Uses a silver-coated flat screen that reflects light more intensely than a white screen.


Screen
Equal to a seven-storey building
21 m
Dwarfs a standard movie screen
29 m

Film format
15/70 – 70mm (2.8in) film with 15 perforations per frame – results in a frame size about ten times that of standard 35mm film, giving IMAX movies incredible clarity.

DID YOU KNOW? *Google's "Cardboard" VR headset is a wearable cardboard frame with a slot for your smartphone – and it works!*

IMAX 3D
Viewers wear glasses with lenses that produce 3D vision.

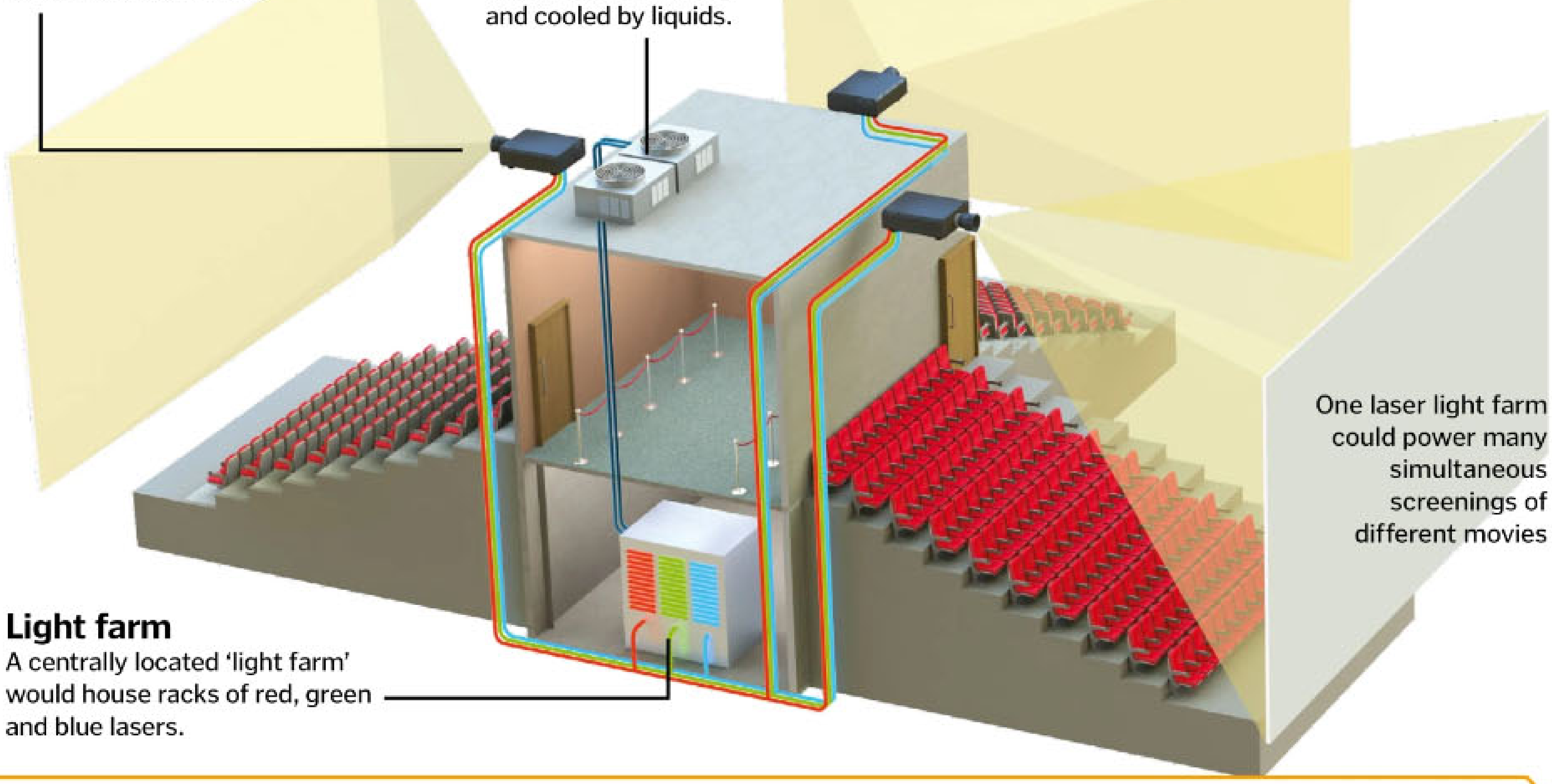


Laser multiplexes of the future

A switch from bulb projectors to laser projectors would open up the possibility of all the screens in a multiplex cinema being fed by one light source. A centrally located 'light farm' would host racks of high-powered red, green and blue lasers connected to a single power supply and cooled by liquids circulating from the cinema's rooftop HVAC system. Light would travel to each auditorium's projector head – fitted with the spatial light modulators and optics to create the moving images and focus them onto the screen – via armoured fibre-optic cables in the walls of the theatre.

In this setup, the laser light farm would be responsible for simultaneous screenings of different movies in each auditorium. The cinema's running costs could be dramatically reduced since there would no longer be a need for dedicated projection booths, and the projectors and light farm could even be controlled by off-site networked operators.

There is still no success in developing quieter popcorn for cinema



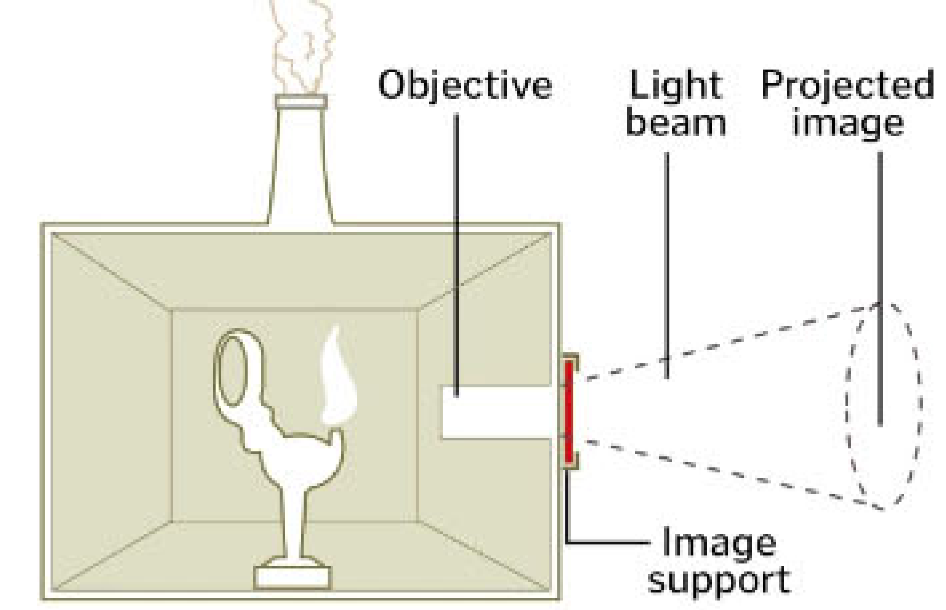
Projector head
Light travels through the projector heads to create moving images.

HVAC cooling system
Lasers are hooked up to a single power supply and cooled by liquids.

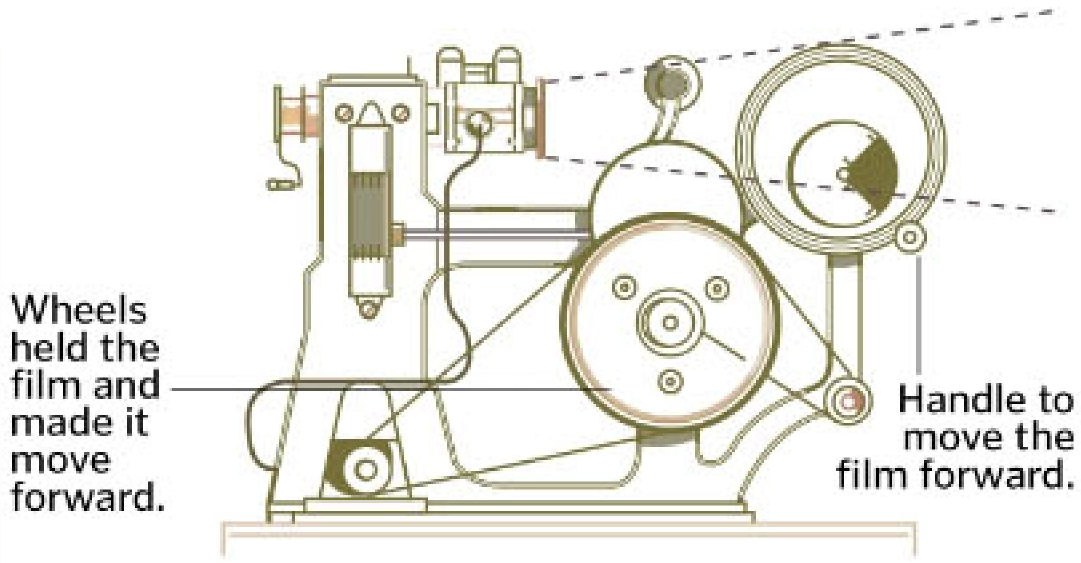
Light farm
A centrally located 'light farm' would house racks of red, green and blue lasers.

One laser light farm could power many simultaneous screenings of different movies

The first projection systems

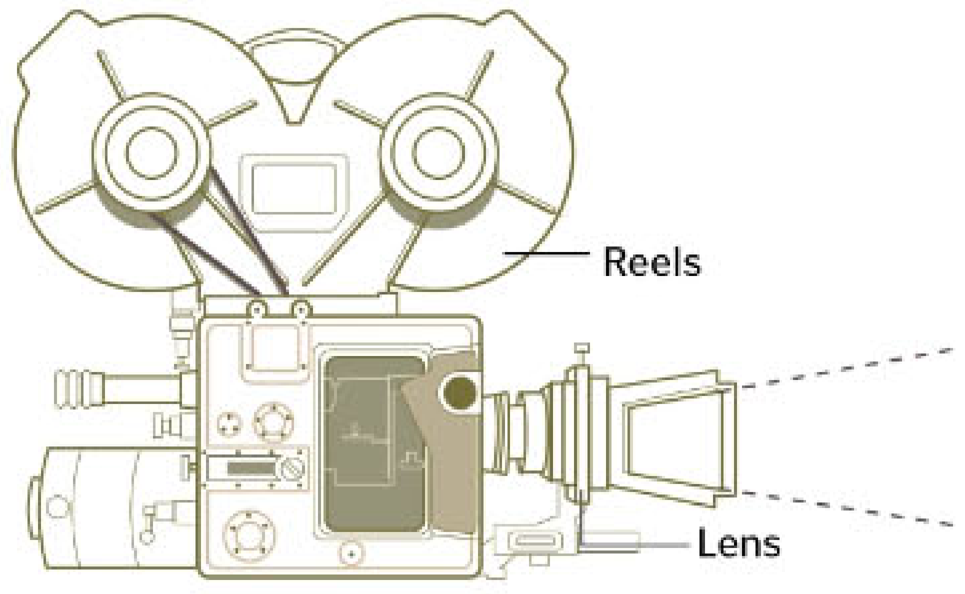


Ca 17th century
The 'magic lantern' was the first system resembling modern projectors. They used candles or oil lanterns as light sources.



Wheels held the film and made it move forward.
Handle to move the film forward.

1895
The Lumière brothers invented a projector that took its mechanical inspiration from a sewing machine, and presented it in Paris.



1932
The rise of colour cinema. Technicolor cameras superimpose three films in red, blue and green to deliver full-colour spectrum images.

© Solgo; Thinkstock

How will we shop?

From robot shop assistants to virtual fitting rooms, this tech will revolutionise retail

The Dandy Lab is testing interactive information screens and smart footfall counters

There is no doubt that the internet has changed the way we shop, with many people preferring to click and buy from the comfort of their own homes instead of venturing out to browse the local stores. The convenience of not having to deal with bustling queues or lug your purchases around is no doubt very appealing, but there are huge benefits for the retailers too.

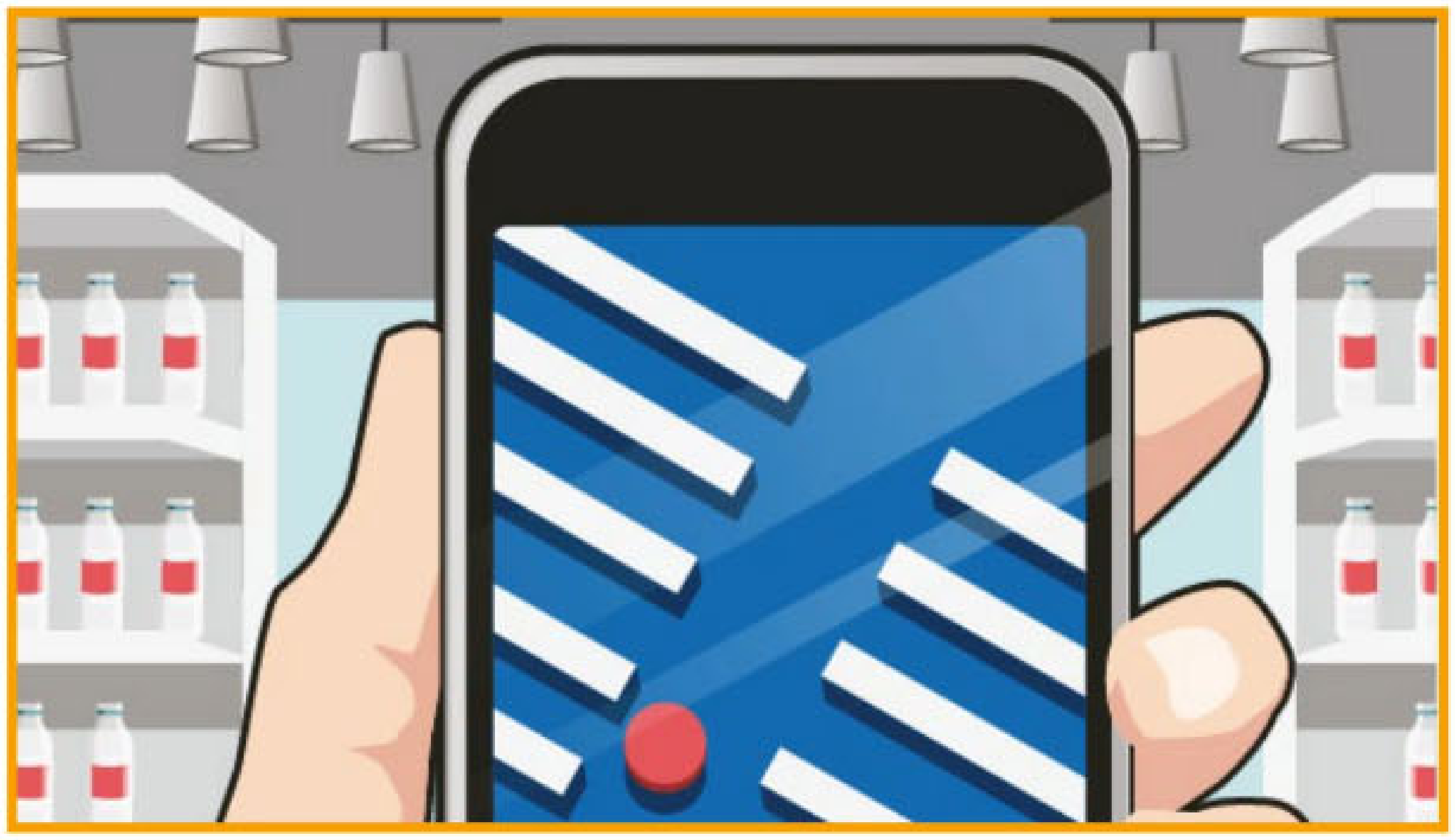
As people peruse their products online, companies can collect lots of useful data about them by way of cookies. These simple text files are downloaded onto your computer when you visit a website and store information about which products you looked at there. The cookies can then be accessed by the retail company, enabling them to target you with adverts based on your preferences, so you will be more likely to take notice. This personalised service often helps to boost sales, but it isn't something the stores on the high street can take advantage of.

With many stores struggling to compete, some clever innovators are developing new technologies that can help them. The Dandy Lab, a menswear and lifestyle outlet in London, is providing a testing ground, enabling companies to try out their ideas on real-life

Lighting the way

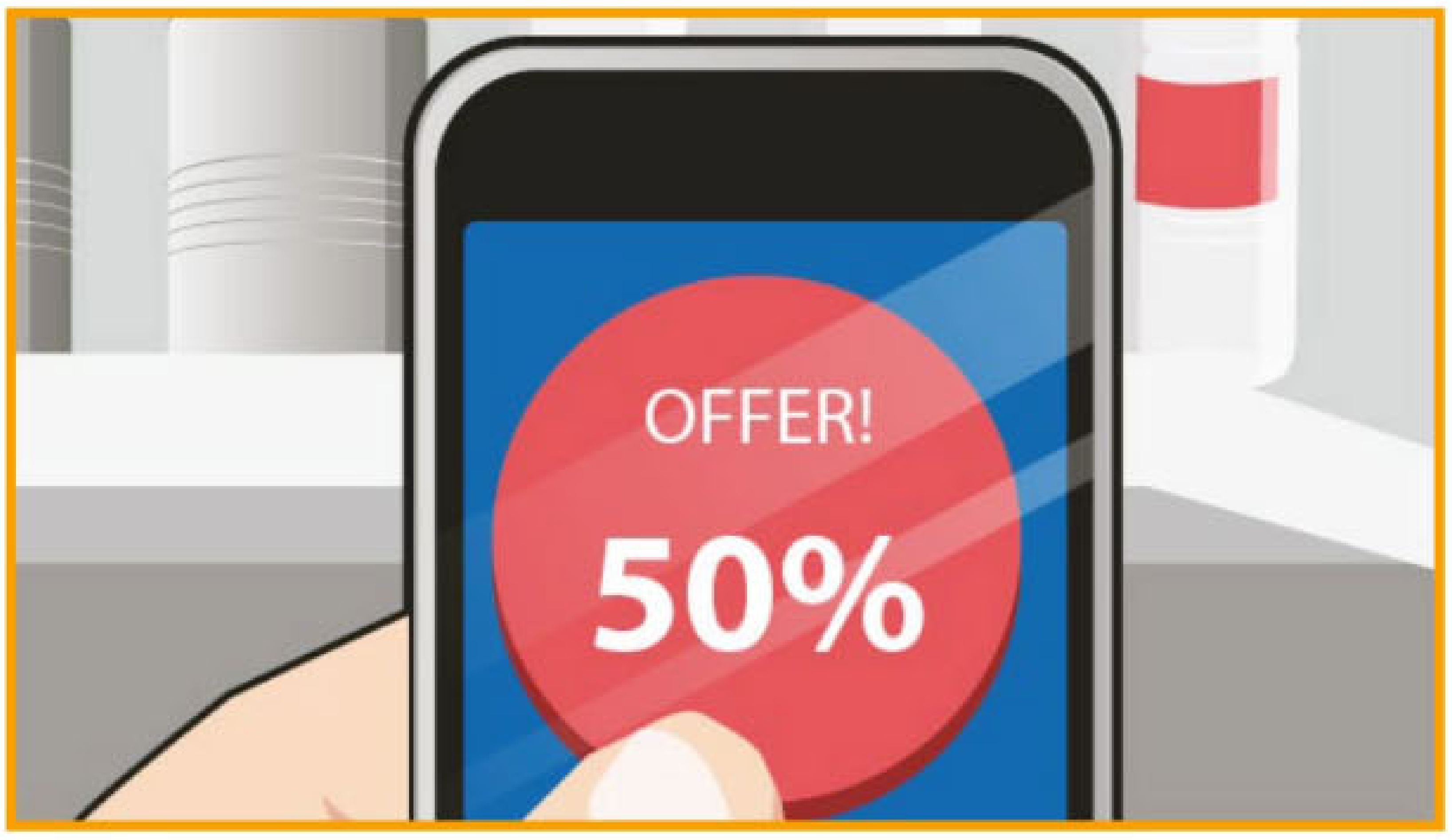
How Philips' system can help you navigate the aisles

1 Emit the signal
When you enter the store, the light fixture above you emits a unique identification code.



2 Find your location
Your smartphone's camera receives the code telling it exactly where you are in the store.

3 Plan a route
An app on your phone plots the most efficient route to the products on your shopping list.



4 Get the deals
As you walk down an aisle, the lights above send discount codes for the nearby products to your phone.

DID YOU KNOW? *Amazon has opened a bookstore in Seattle, with online reviews shown next to the books on the shelves*

customers. "At the moment there is a lot of tech for online shops, but there is nothing really happening in the brick and mortar environment," says co-founder Julija Bainiaksina. "We wanted to see how we can integrate technology in-store and make the shopping journey from online to offline seamless and more convenient for the customer."

The 'clothes-store meets retail technology lab' is currently trialling several new methods for enhancing the shopping experience. These include smart mannequins that can send information about the clothes they are wearing to the customers' phones, and a mobile payment app that enables you to use your phone to scan a product's barcode, pay for it and take it home without having to queue at all. The shop is also attempting to replicate online 'cookie' technology with a smart loyalty card scheme that helps shop assistants provide a more personalised service. "We give every single customer a loyalty card containing an RFID [radio-frequency identification] chip, and at the door we have an RFID reader," says Julija. "Once the customer comes back to the shop, we instantly receive information about what they bought, what they like and so on. This gives our sales staff a better understanding of the customer, so they can recommend products based on their previous purchases."

For Julija, using this new technology is not about competing with online retailers but helping online and offline shopping to complement each other. "For physical shops, the main benefit is the ability to showcase their products and provide an experience," she explains. "What we found out is that a lot of people come to the shop just to try on the products, touch them, feel them, and see if they really want them, and then they go home and buy them online. Alternatively, they might do research online, and then come into the shop to try something on and buy it. So both of those channels – online and offline – need to work with each other. The technology should somehow fuse them together to provide one seamless shopping experience for the customer."

In the future, it could be that shops simply become showrooms, stocking tester products for you to try before you purchase them via interactive display screens. Alternatively you may not need to visit the shop at all, instead using a virtual reality helmet to browse and even interact with the products before you part with your cash. In the meantime though, there are plenty of changes already appearing on the high street. From Bluetooth beacons that help you bag a bargain to augmented reality mirrors that let you try on clothes without getting changed; a trip to the mall is about to get a lot more high-tech.

> *"Smart mannequins can send information about the clothes they are wearing to the customers' phones"*

Virtual reality shopping

Imagine being able to wander around a shop and try out the products without ever leaving your house. With several virtual reality headsets now available, this fantasy is fast becoming reality, enabling you to experience the fun of shopping without the stress of crowds or queues. It can also open up some unique try-before-you-buy opportunities. Teaming up with Microsoft Hololens, car manufacturer Volvo was able to create a virtual showroom, allowing customers to strip down holograms of its cars and watch the vehicles in action. Virtual reality production company Visualise has also made it possible for customers of travel agent Thomas Cook to experience holiday destinations before booking a trip.

The growth of virtual reality will enable you to explore shops from the comfort of your home

Volvo's virtual reality showroom lets customers see the inner workings of its cars

Beacon bargains

Everyone loves a bargain, and thanks to a new retail technology, they are becoming easier than ever to find. Devices called beacons are small Bluetooth transmitters that can be installed in shops and communicate with smartphones of passers-by. Already being used on London's Regent Street, the beacons can send exclusive deals to an app on your phone when you walk past a shop, encouraging you to step inside and snap up the offer.

While these beacons can detect when you are nearby, Philips' connected lighting system has taken things even further. The LED lights it has installed along the aisles of a Carrefour supermarket in Lille, France, can work out exactly where you are in the store, and send deals for products in close proximity. The technology is called Visible Light Communication, which uses rapidly flickering LEDs to emit signals that are picked up by your smartphone's camera sensor.

Beacons installed in 'smart mannequins' can tell you exactly what they are wearing

Illustrations by Edward Crooks

The mall of 2020

The high-tech breakthroughs that will change the way you shop

Sensors and trackers

Knowing more about the people who walk into their store can help retailers provide personalised customer service. However, instead of using intrusive facial recognition, Hoxton Analytics has developed a footfall counter that gathers data from people's shoes. A camera records their feet as they walk into the store, and a processor uses clever algorithms to determine their likely age, gender and what brands they like. Other sensors can also track the Wi-Fi pings from customer's smartphones to track where they look in the store.

Information screens

With shops only capable of stocking so many products, some are already including digital displays that let customers access the entire catalogue if they can't find what they want in-store. In the future this could lead to virtual stores, such as the experiment by South Korean store Homeplus. Images of their products were displayed on the walls of a subway station, and by scanning a QR code on their phone commuters could order online and have them delivered by the time they got home.

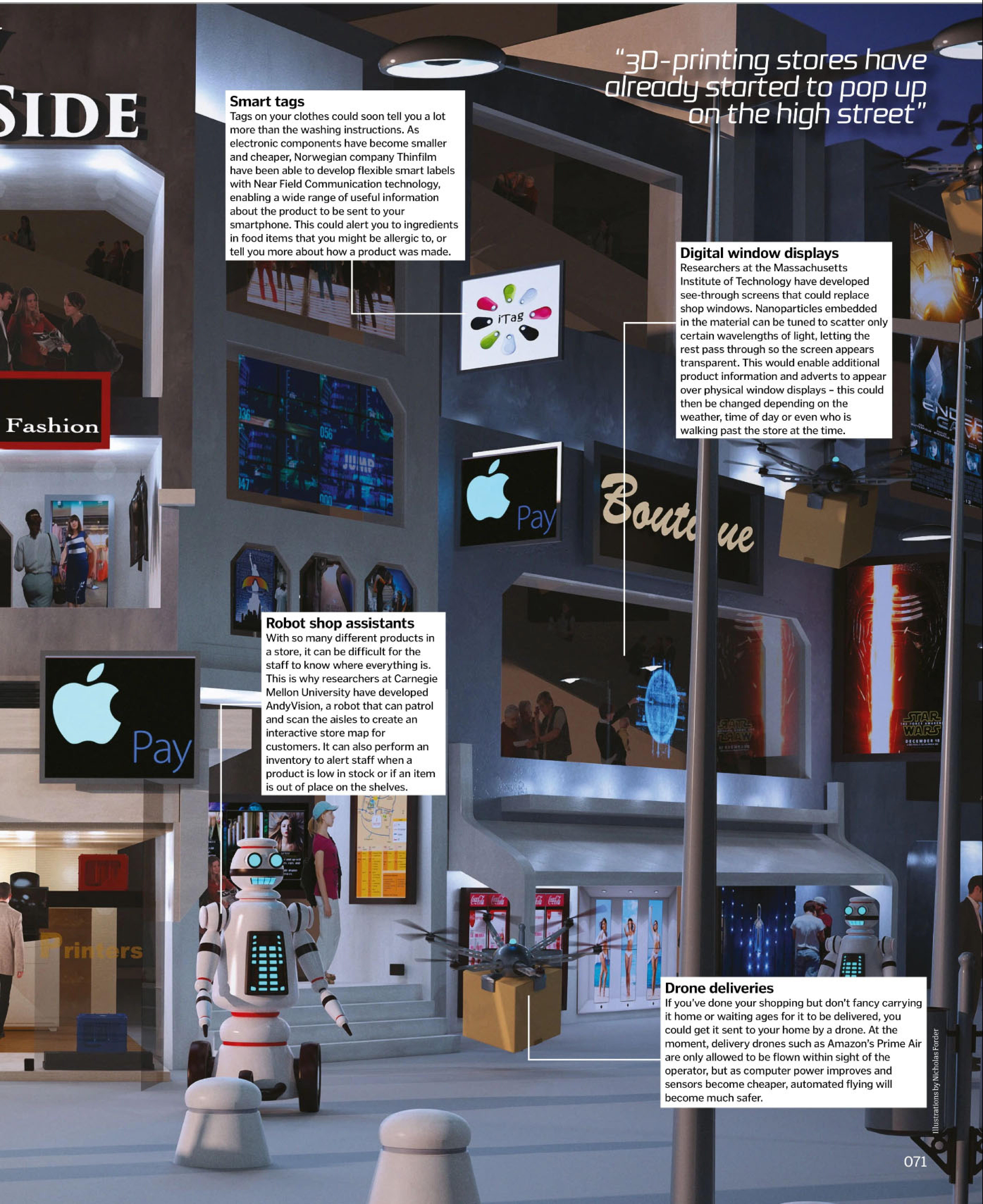
Virtual fitting rooms

Instead of having to get changed to try on a new outfit, images of the new clothes can be superimposed over live footage of you on the fitting room 'mirror'. The Magic Mirror uses a Kinect body sensor to monitor your position so it can ensure correct placement of the garment on a screen. You can then select a new outfit via gesture or touch screen control, and even take a picture of your new look to send to your friends for approval.

3D printers

As well as selling 3D-printed products, some stores are already letting you print your own. A variety of 3D-printing stores have already started to pop up on the high street and could be a staple of shopping malls in the near future. Customers will be able to download a design or create their own. They can then have the product made while they wait or send their design to the shop and pick up the finished product later.

DID YOU KNOW? *Tesco petrol stations have trialled using facial recognition software to provide targeted adverts at the checkout*



> *"3D-printing stores have already started to pop up on the high street"*

Smart tags

Tags on your clothes could soon tell you a lot more than the washing instructions. As electronic components have become smaller and cheaper, Norwegian company Thinfilm have been able to develop flexible smart labels with Near Field Communication technology, enabling a wide range of useful information about the product to be sent to your smartphone. This could alert you to ingredients in food items that you might be allergic to, or tell you more about how a product was made.

Digital window displays

Researchers at the Massachusetts Institute of Technology have developed see-through screens that could replace shop windows. Nanoparticles embedded in the material can be tuned to scatter only certain wavelengths of light, letting the rest pass through so the screen appears transparent. This would enable additional product information and adverts to appear over physical window displays – this could then be changed depending on the weather, time of day or even who is walking past the store at the time.

Robot shop assistants

With so many different products in a store, it can be difficult for the staff to know where everything is. This is why researchers at Carnegie Mellon University have developed AndyVision, a robot that can patrol and scan the aisles to create an interactive store map for customers. It can also perform an inventory to alert staff when a product is low in stock or if an item is out of place on the shelves.

Drone deliveries

If you've done your shopping but don't fancy carrying it home or waiting ages for it to be delivered, you could get it sent to your home by a drone. At the moment, delivery drones such as Amazon's Prime Air are only allowed to be flown within sight of the operator, but as computer power improves and sensors become cheaper, automated flying will become much safer.

Illustrations by Nicholas Forder

TRAVEL 2050

YOUR TICKET TO THE HIGH-TECH HOLIDAY OF THE FUTURE

It's 2050 and taking a vacation is easier than ever, thanks to the latest technological breakthroughs. Over the next few pages, we'll guide you through every step of your trip, from planning and booking, to travelling and making the most of your stay.

Some of the technology involved might seem unbelievable, but all of it was already real, or under development, in 2016. Take the process of booking your trip; you may have been using comparison websites to find the best deals, but now you don't need to enter your information, as online travel agents already know your preferences. Gareth Williams, CEO and co-founder of travel company Skyscanner, said: "Travel search and booking will be as easy as buying a book on Amazon."

There's no longer any guesswork involved in picking your holiday destination either, as Nik Gupter, Skyscanner's director of hotels, already predicted back in 2016: "In ten years' time a traveller will be able to take a virtual reality walk through the hotel he is planning to book in real-time."

The stress of travelling is long gone and getting to your destination is almost as enjoyable as the holiday itself. In 2016, Melissa Weigel from design studio Moment Factory said: "In the near future, airports will be an intrinsic part of the holiday experience." Since then, automated check-in and speedy security scanning has made boarding your flight a breeze.

Holiday destinations have also changed a great deal, as futurist Daniel Burrus predicted: "Relatively affordable trips in low Earth orbit that enable you to experience a few minutes of weightlessness will happen very soon." Now we've our sights on the Moon and Mars.

CHOOSE YOUR MODE OF TRANSPORT

Dassault Systèmes' concept for a flying cruise liner

The Spike S-512 jet will mirror the speed of Concorde

Avoid the airport altogether by taking your TF-X flying car

The 90-metre luxury JAZZ yacht features an indoor pool

© Zaha Hadid Architects/Bloom+Voss Shipyards/Moka-Studio

DID YOU KNOW? *Disney's Revel interface can convey the feel of rough terrain as you slide your fingers across a map*

BOOKING YOUR HOLIDAY

Get the VIP treatment from the off

Choose a destination

Social media and online retailers use members' profiles to monitor activity and alter the content they see. Travel brands now operate in a similar way, logging your likes and dislikes, while facial coding algorithms, as developed by Affectiva, enable search engines to read human expressions and gauge how happy you are with the results.

Use an e-agent

You can rent an artificially intelligent e-agent from your local travel company to help plan your trip. The tech is similar to JIBO – the personal assistant released in 2015 that uses two hi-res cameras to recognise faces and algorithms to learn your preferences and adapt.

Take a virtual vacation

VR headsets enable you to try before you buy. By using dual lenses with a slightly different image in front of each eye, it recreates your normal stereoscopic vision and fools your brain into thinking virtual worlds are real. Disney's Revel system, developed in 2012, uses electrical signals to create the feeling of touch.

Book with ease

While apps like Expedia enabled 2016 holidaymakers to arrange most aspects of their trip, 2050 takes the tech a step further. You can use a one-stop app to book your flights, hotel and holiday activities with a couple of taps of your smartwatch. Even transport to the airport will be taken care of.

AT THE AIRPORT

How tech will take the stress out of travelling

Smart tags

As you drop off your bags, they're fitted with tags containing Near Field Communication (NFC) chips. When they come into close contact with another NFC chip inside the scanner, your personal and flight data is transferred wirelessly. You can then track each scan via an app.

Biometric scans

Instead of a passport, a biometric data card is used to identify you. Images of your eye, taken with a camera that records visible and infrared light, capture the exact position of the iris' unique patterns and features. As you board the plane, your eyes are scanned and matched.

Speedy checks

The Picosecond Programmable Laser is a scanner that vibrates the molecules in your body and possessions to identify different substances, from traces of gunpowder to the contents of your stomach. It's 10 million times faster than a conventional scanner.

ON THE PLANE

Your journey will fly by as you explore the onboard entertainment options

Instead of waiting around at the gate, you are free to explore the airport's rooftop gardens, art exhibitions and shops at your leisure, safe in the knowledge that a 3D holographic assistant will appear to tell you when the plane is boarding.

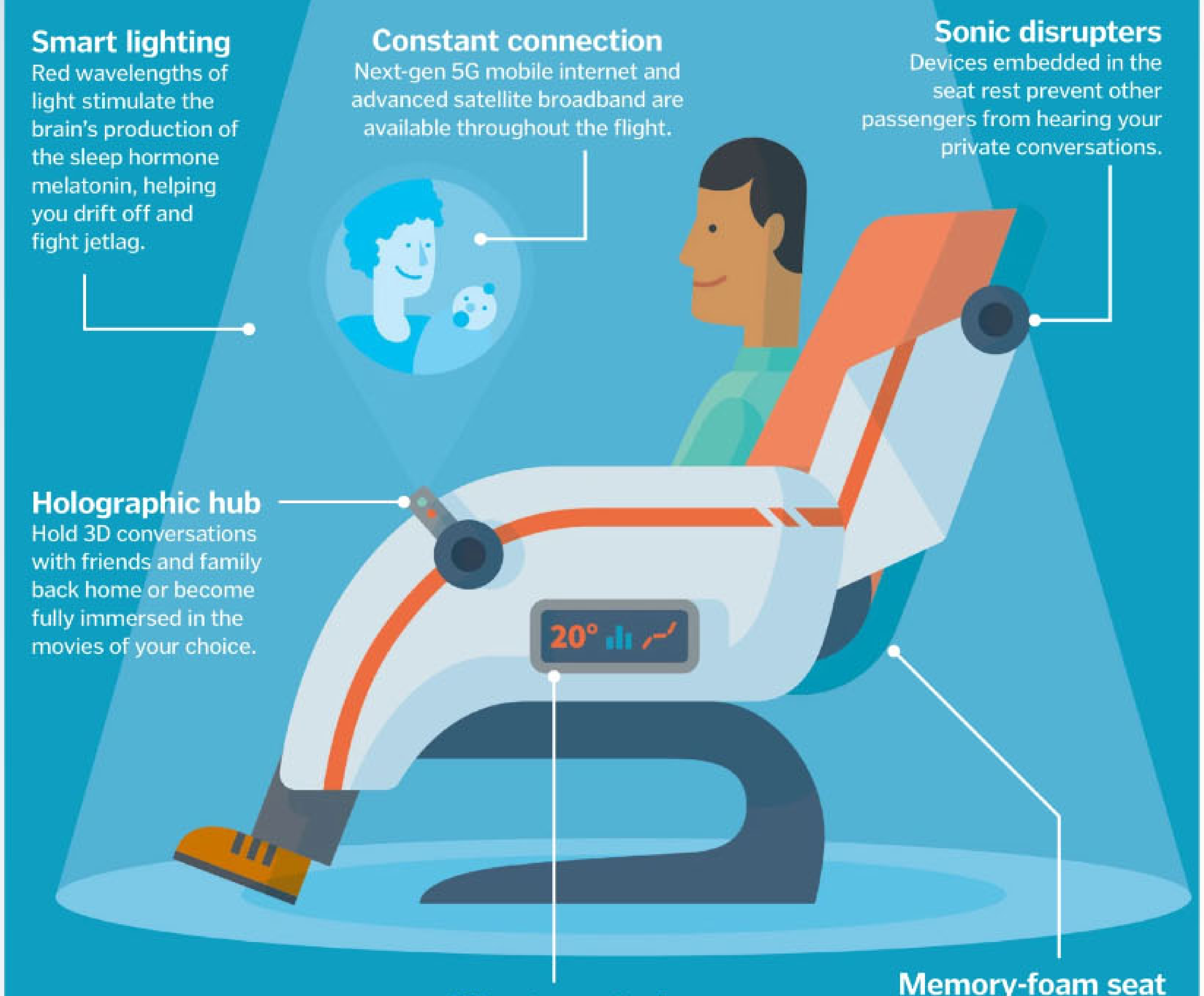
Holograms have been around since the development of lasers in the 1960s, but recent advancements in technology mean they're now much more impressive. They used to be created by splitting a laser beam in two and directing each beam towards an object using mirrors. The beams were then reflected off the object and at the point where they recombined, a still hologram of the original object formed. In recent years, we've mastered moving holographic images, resulting in ultra-realistic 3D content for entertainment and practical uses.

When it's time to stroll onto the plane, you'll find that the Airbus Concept Cabin has become reality, and you're no longer confined to your own seat. First class and economy have been replaced with zones tailored to your different needs, whether you want to relax, mingle with other passengers or play some games.

Sit back, relax and fly

CONCEPT

Skyscanner's personalised aircraft seat concept will provide ultimate comfort on your journey



Smart lighting
Red wavelengths of light stimulate the brain's production of the sleep hormone melatonin, helping you drift off and fight jetlag.

Constant connection
Next-gen 5G mobile internet and advanced satellite broadband are available throughout the flight.

Sonic disrupters
Devices embedded in the seat rest prevent other passengers from hearing your private conversations.

Holographic hub
Hold 3D conversations with friends and family back home or become fully immersed in the movies of your choice.

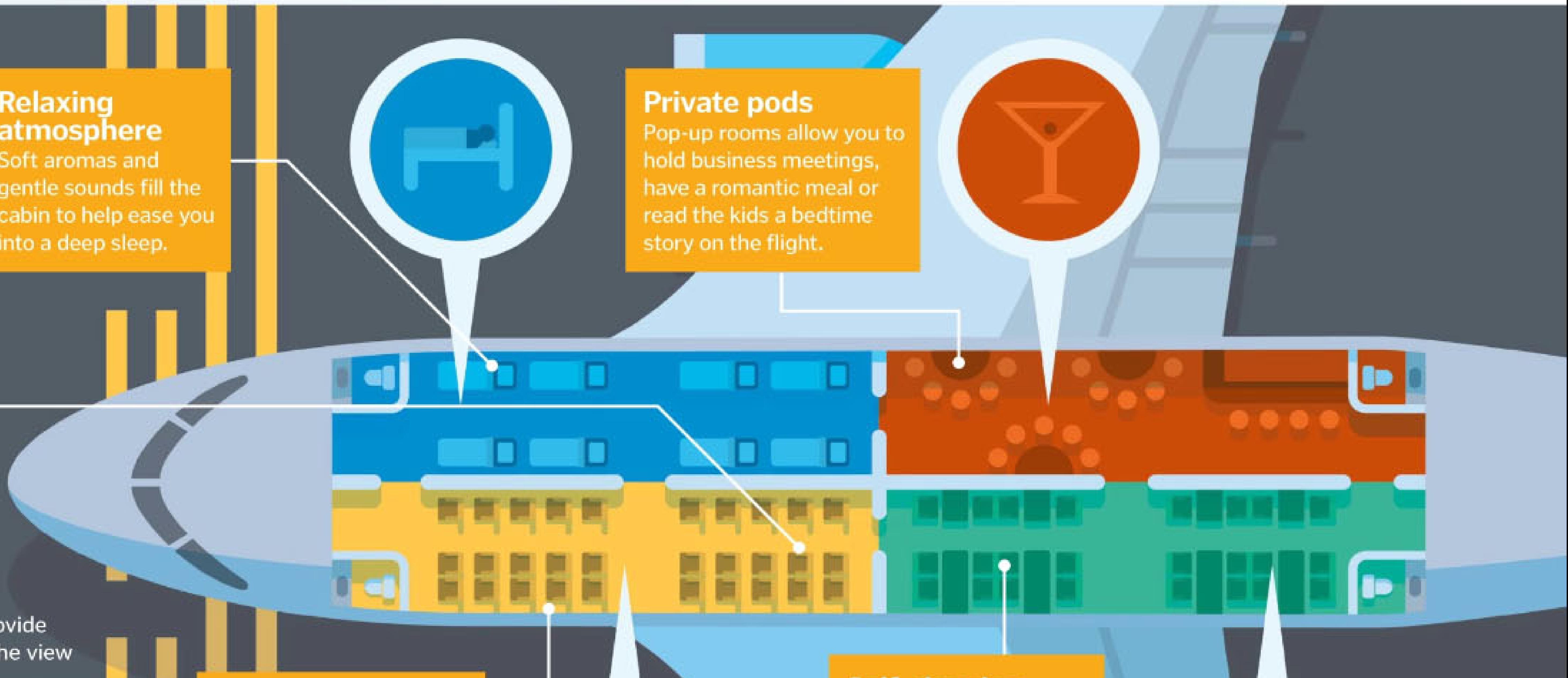
Climate control
Built-in climate control lets you monitor and adjust heating and cooling systems for your individual seat.

Memory-foam seat
The roomy aircraft seat moulds to your body shape, providing comfortable support that minimises back pain.

CONCEPT

Modular aircraft

A cabin design with zones for work, rest and play



Relaxing atmosphere
Soft aromas and gentle sounds fill the cabin to help ease you into a deep sleep.

Private pods
Pop-up rooms allow you to hold business meetings, have a romantic meal or read the kids a bedtime story on the flight.

Immersive entertainment
Practise your tennis or golf at the virtual gaming wall or put on a VR headset to be transported to a cinematic world.

Panoramic views
With the wave of a hand, the aircraft wall becomes transparent, offering a spectacular view of the outside world.

Self-cleaning
Dirt repellent coatings inspired by nature ensure the aircraft's fittings and furnishings are kept in good condition.

Interactive window displays provide interesting information about the view

DID YOU KNOW? *Self-service kiosks at Incheon airport in South Korea allow a three-minute check-in for eight major airlines*

YOU HAVE REACHED YOUR DESTINATION

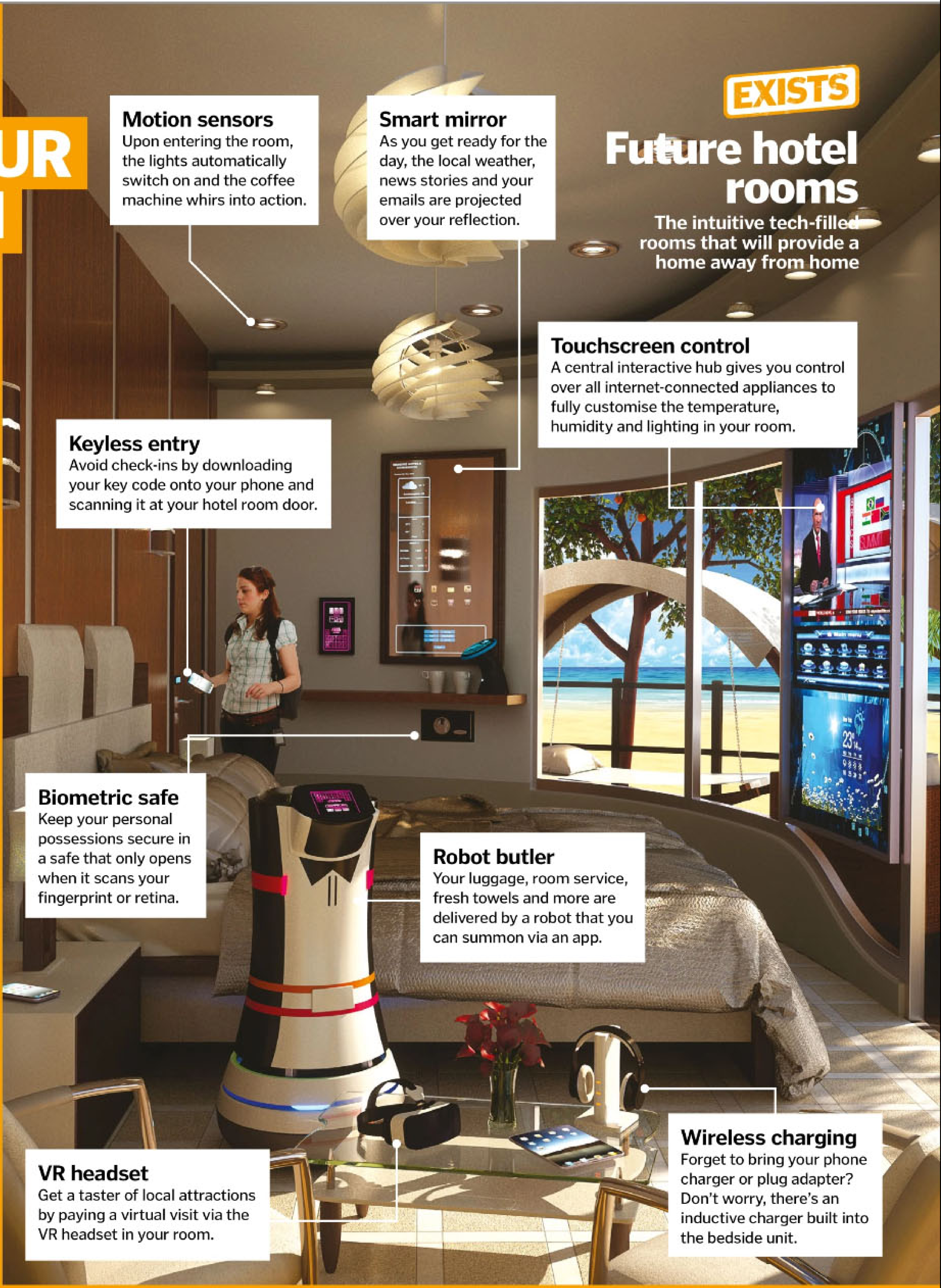
The smart hotel room will ensure the stress-free experience continues

Once you've stepped off the plane and swiftly passed through immigration with your biometric card, you will find another driverless taxi waiting to take you to your hotel. Instead of having to pick up your room key at the check-in desk, you can proceed straight to your room and unlock it using your smartphone, a system that was adopted early by Hilton and Marriott hotel chains.

Your bags are delivered to your door by a robot butler, such as Botlr, the droid employed by Aloft Hotels at their Californian establishments. He can be summoned via an app to bring you any toiletries you may have forgotten to pack, or deliver a tasty snack to help you refuel after your long journey.

Just as everything in your own home is connected to the internet, all of your hotel room's appliances are smart and intuitive too. You can even upload your home temperature preferences to the room's Nest thermostat, and display family photos on the digital wall displays, to help you feel really at home.

A good night's rest is guaranteed as the Sleep Number x12 bed features sensors that monitor your sleep, ensuring the alarm clock gently wakes you at the optimum time, and can tilt the pillows to stop your partner snoring. All of this tech already existed as of 2016, but has since been adopted by hotels throughout the world.



EXISTS

Future hotel rooms

The intuitive tech-filled rooms that will provide a home away from home

Motion sensors
Upon entering the room, the lights automatically switch on and the coffee machine whirs into action.

Smart mirror
As you get ready for the day, the local weather, news stories and your emails are projected over your reflection.

Touchscreen control
A central interactive hub gives you control over all internet-connected appliances to fully customise the temperature, humidity and lighting in your room.

Keyless entry
Avoid check-ins by downloading your key code onto your phone and scanning it at your hotel room door.

Biometric safe
Keep your personal possessions secure in a safe that only opens when it scans your fingerprint or retina.

Robot butler
Your luggage, room service, fresh towels and more are delivered by a robot that you can summon via an app.

VR headset
Get a taster of local attractions by paying a virtual visit via the VR headset in your room.

Wireless charging
Forget to bring your phone charger or plug adapter? Don't worry, there's an inductive charger built into the bedside unit.

WEIRD HOTELS THAT ACTUALLY EXIST

© ICEHOTEL/Paulina Holmgren

The frozen hotel

Made entirely from 'snice' – a mixture of snow and ice – the Icehotel in Sweden melts in the summer and is rebuilt every winter, with construction taking just six weeks. Temperatures inside the hotel are between -5 and -7 degrees Celsius.

The salt palace

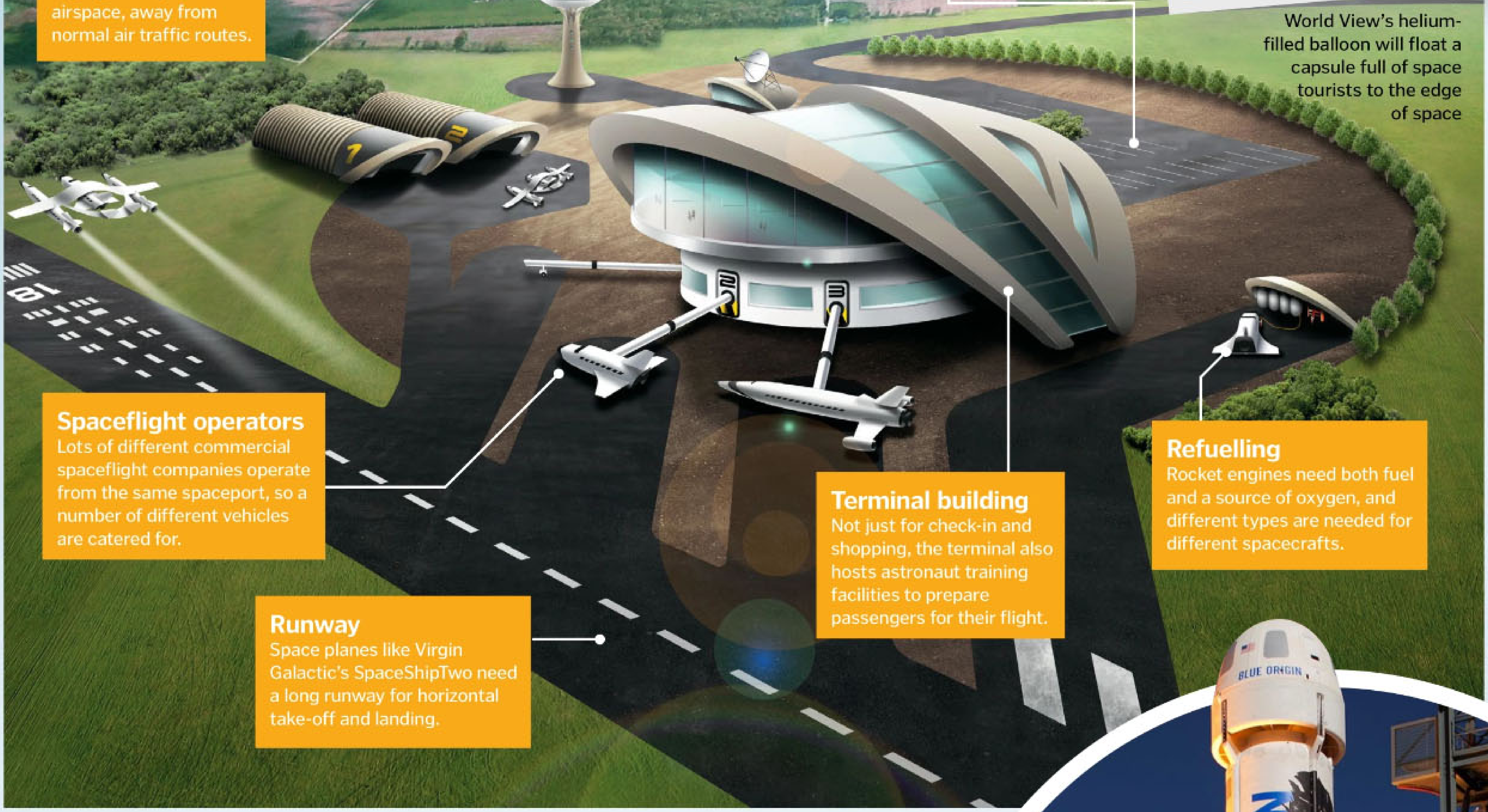
Located on the edge of the world's largest salt flats in Bolivia, the Palacio de Sal has been built using one million blocks of salt and features 16 rooms, a spa and a golf course. Everything from the walls to the beds is made entirely from salt.

The jumbo experience

If you haven't had enough of airplanes by the time you leave the airport, then Jumbo Stay will let you dwell in one too. The converted 747-200 jumbo jet is grounded near Arlanda Airport in Sweden and features over 30 rooms.

At the spaceport IN DEVELOPMENT

Catch a space plane into orbit from your local spaceflight hub



Airspace
Space plane operations are conducted in segregated special-use airspace, away from normal air traffic routes.

Remote location
Due to the higher risk involved with rocket vehicles, spaceports are located away from densely populated areas.

Spaceflight operators
Lots of different commercial spaceflight companies operate from the same spaceport, so a number of different vehicles are catered for.

Terminal building
Not just for check-in and shopping, the terminal also hosts astronaut training facilities to prepare passengers for their flight.

Refuelling
Rocket engines need both fuel and a source of oxygen, and different types are needed for different spacecrafts.

Runway
Space planes like Virgin Galactic's SpaceShipTwo need a long runway for horizontal take-off and landing.

World View's helium-filled balloon will float a capsule full of space tourists to the edge of space

SPACE TOURISM

Take a trip that's literally out of this world

If you really want to escape from it all, then how about leaving the planet altogether? Space tourism is a billion dollar market in 2050 and there are several companies offering trips. Blue Origin, the company set up by Amazon founder Jeff Bezos, can offer you breathtaking views from its New Shepard spacecraft as you soar over 100 kilometres above Earth.

You'll need to arrive at the desert launch site in West Texas two days before your flight so you can begin your astronaut training. You'll receive mission and vehicle overviews, in-depth safety briefings and instructions on how to move in a weightless environment. When the morning of your flight arrives, it's time to scale the steps of the launch tower and climb through the hatch of the capsule, which sits on top of an 18-metre tall rocket.

Once you're strapped in and have received final clearance for launch, the countdown to lift-off will begin. The extreme acceleration will force you back into your seat and you'll experience over 3 g for 150 seconds and then the booster engine will cut off as you glide into space. The capsule will separate from the booster, and from the serene silence will come the signal to release your harness.

As you float out of your seat and marvel at the weightless freedom, you'll forget that you're travelling faster than Mach 3 – three times the speed of sound – and stare back at Earth out of the capsule window. Before descent, you will return to your seat to strap in for re-entry. Forces of over 5 g will push against you before the parachutes deploy and thrusters fire, reducing your speed as you gently float back to Earth. Once you've landed, just miles from where you launched, you can go and collect the complimentary souvenirs of your thrilling trip. That's right; novelty keyrings still exist in 2050.

Blue Origin first vertically landed a booster in 2015, paving the way for reusable rockets

XCOR Aerospace is planning to launch its Lynx spaceplane from its Curaçao spaceport

DID YOU KNOW? *The first space tourist was US multimillionaire Dennis Tito, who paid $20m to spend eight days on the ISS in 2001*

UNDERWATER HOTELS

Sleep, eat and relax with the fishes

Back in 2016, the closest thing to an underwater suite was the five-star Atlantis, The Palm, in Dubai. The floor-to-ceiling views of a colossal aquarium created such a spectacular illusion that celebs like Kim Kardashian West were willing to splash the cash to stay there.

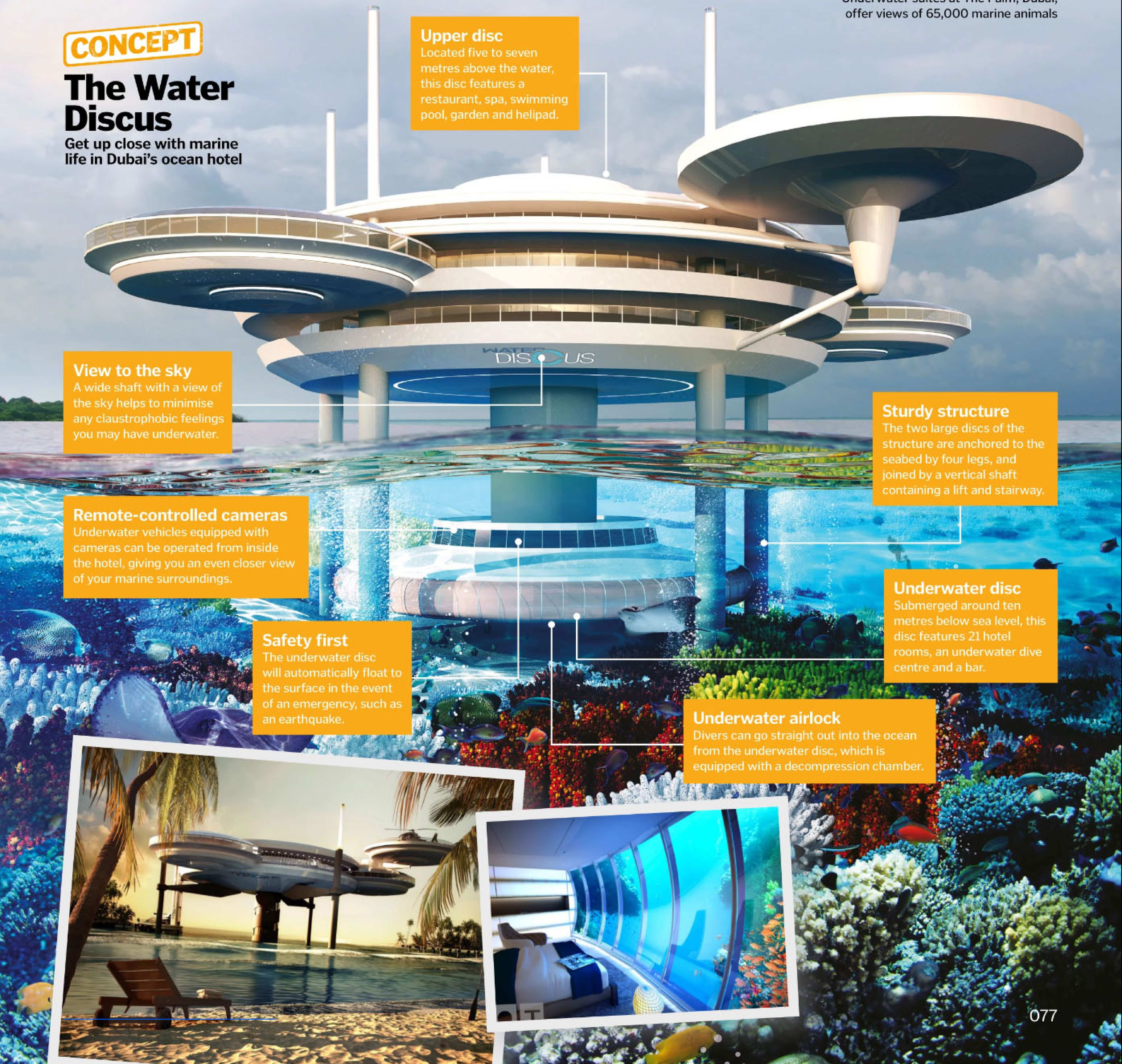
But while a fully-fledged underwater haven like the Water Discus Hotel was just a concept in 2016, its doors are open in Dubai in 2050. Once you arrive by boat or helicopter from the shore, you can relax in your room and watch the marine critters swim by, or sign up for a diving course to get even closer to the action. You don't even need to go back up to the surface in order to get in the water, as there's sea access direct from the underwater disc.

Underwater suites at The Palm, Dubai, offer views of 65,000 marine animals

CONCEPT

The Water Discus

Get up close with marine life in Dubai's ocean hotel



Upper disc
Located five to seven metres above the water, this disc features a restaurant, spa, swimming pool, garden and helipad.

View to the sky
A wide shaft with a view of the sky helps to minimise any claustrophobic feelings you may have underwater.

Sturdy structure
The two large discs of the structure are anchored to the seabed by four legs, and joined by a vertical shaft containing a lift and stairway.

Remote-controlled cameras
Underwater vehicles equipped with cameras can be operated from inside the hotel, giving you an even closer view of your marine surroundings.

Underwater disc
Submerged around ten metres below sea level, this disc features 21 hotel rooms, an underwater dive centre and a bar.

Safety first
The underwater disc will automatically float to the surface in the event of an emergency, such as an earthquake.

Underwater airlock
Divers can go straight out into the ocean from the underwater disc, which is equipped with a decompression chamber.

THE FUTURE OF TEACHING

WHAT WILL SCHOOLS BE LIKE IN 2050?

The modern-day classroom isn't really all that different from a Victorian classroom. The teacher still stands at the front, with the children facing them, answering questions and taking hand-written notes. While there isn't a cane, and we've swapped squeaky chalk for marker pens, the format hasn't really evolved.

It's strange when you consider the advancements that we've made in the same amount of time: we've landed on the Moon, unravelled the human genome and created super-computers you carry in your pocket. So why is education stuck in the 20th century?

In some schools, it isn't; advancements in teaching, communication and technology have totally changed the working environments of students around the world, and the future only holds more progress. Looking closer at that modern day classroom reveals some details you may have missed at the first pass. Those hand-written notes might be taken on an iPad with a stylus, with the handwriting converted into typed text and the finished document saved to the 'cloud'. The board is interactive, and can display websites, videos and more that the teacher can control with a smart remote.

In fact, while the basic format of teaching may remain largely unchanged, technology has improved how kids learn, what they learn, and how they are taught. Textbooks are, of course, still a big part of the school experience, but increasingly e-books and online research are being used in place of the traditional tomes. In some schools, students are loaned iPads or other tablets, loaded with their entire reading list for the year. Rather than straining their spines by carrying huge backpacks, pupils only need one device. Even better, they can make helpful notes on the pages, or highlight useful sections, without being charged for defacing the book.

Of course, these books can also include links to websites that aid learning. Digital pages can contain useful information for additional study or homework, or can even take students to online tests. The teacher can then check in on who has taken the test, how they scored, and get more information about each pupil, including how long they spent working on each question.

The internet has become a valuable teaching resource and is regularly used in the classroom. Rather than formal videos recorded in the days of VHS, teachers can quickly find useful resources and play them to the class. Not only is this more engaging than a video that's decades old, it can also prompt further discussion.

Technological advancements have changed the way teachers work, too. More and more, students are being encouraged to work in small groups and foster interaction, with technology as an enabler. Learning spaces are being redesigned to reflect this, and teachers' roles are slowly changing to a more passive role.

And as technology becomes more and more accessible, this will only increase. Tech like 3D printing will allow students and teachers alike to create teaching materials within minutes. 3D modelling lessons will be able to go from the design to the prototyping stage within a few hours, while lessons about biology will see teachers printing out 3D models of ancient animal skulls to pass around the class. Cloud computing will eradicate excuses like "the dog ate my homework", and give classmates a chance to discuss their work at home, using teacher-controller chatrooms that allow them to collaborate on projects. Gaming will increasingly be used to teach, and eye-tracking will help teachers analyse what works best in the classroom, and what is failing to grab attention.

Of course, as teaching changes, so will the curriculum. For example, as computing skills are becoming more important in this digital age, many students are learning how to program. In the UK, pupils as young as five are being taught how to code, with simple games showing them the basics.

The idea of every student having a tablet won't seem odd in ten years

TABLETS OVER TEXTBOOKS

In the coming years, the idea of carrying around piles and piles of heavy books for each school day will likely be a thing of the past. Whether it's schools providing their pupils with tablets, or students bringing in their own computer devices, the future of the textbook is clearly in a touchscreen display. A single tablet can hold an entire year's worth of learning materials, as well as providing students with interactive tests, videos and apps, controlled by the school. In some schools in the US, this is already happening, and it's undoubtedly the first step in a teaching revolution.

Games will be used as part of coding lessons, helping children to have fun while they learn

GAMING AND LEARNING

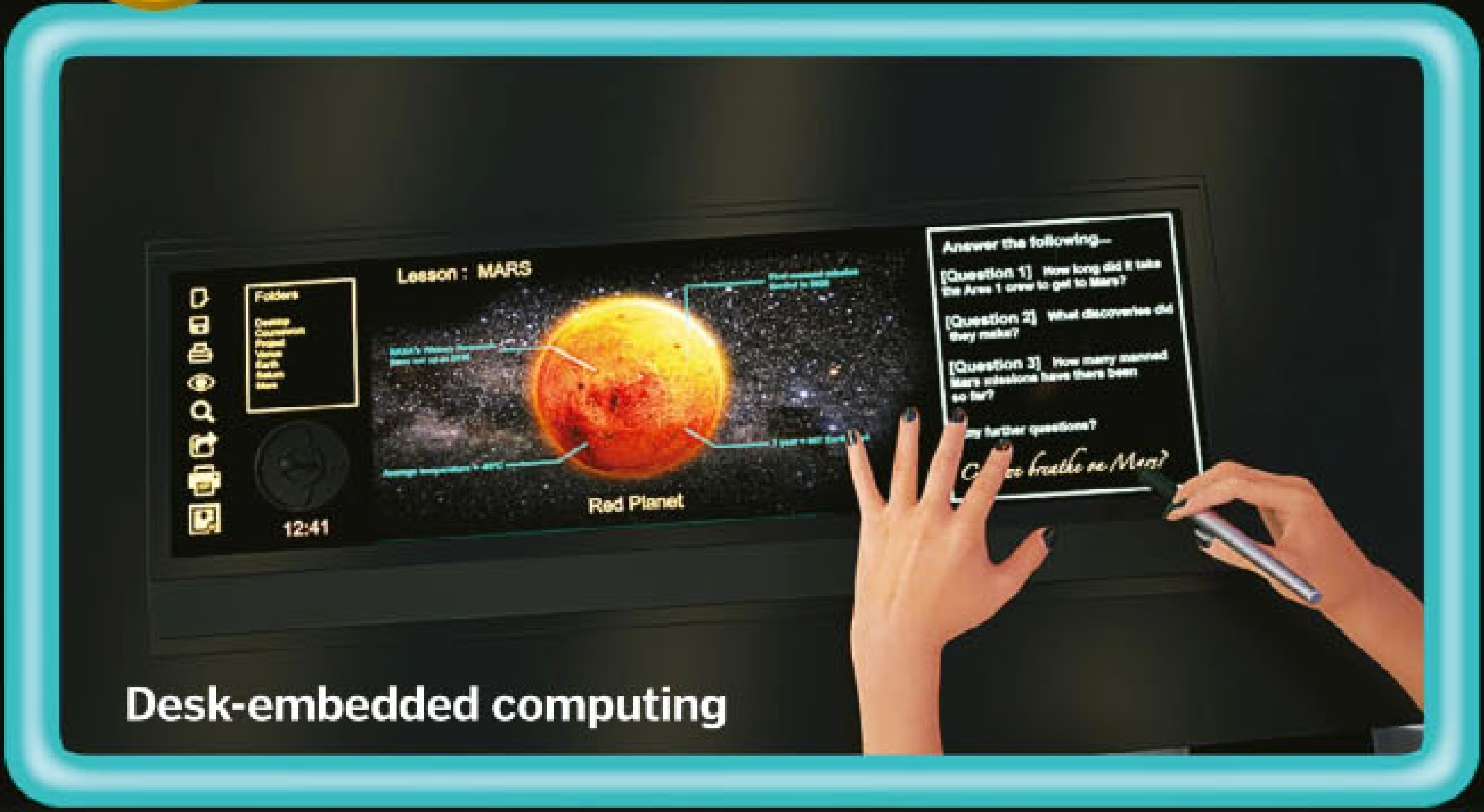
Many teachers and parents assume video games are unnecessarily violent and highly addictive, and without educational merit. But in recent years games have started making their way into the classroom as learning materials. Games like Minecraft, which now has a dedicated Education Edition, can teach children through play. And kids who usually go home and spend hours of their free time on games like this are enjoying learning more than ever. Using games in the classroom will only increase as coding lessons become more commonplace in the near future.

Virtual reality will let students take trips through history and into space

VIRTUAL REALITY LESSONS

Soon, classes won't need to leave the school to take a field trip. Virtual reality headsets will allow students to journey across the world, and even dive beneath the waves or float through space, without ever leaving the room. As this technology becomes more affordable and software developers begin to create virtual learning spaces, lessons will become more engaging and immersive than ever before. Pupils could soon find themselves learning about volcanoes from the edge of Mount Etna, exploring ancient dig sites in Egypt, or even taking a trip through the human body to study anatomy.

© Alamy; Thinkstock

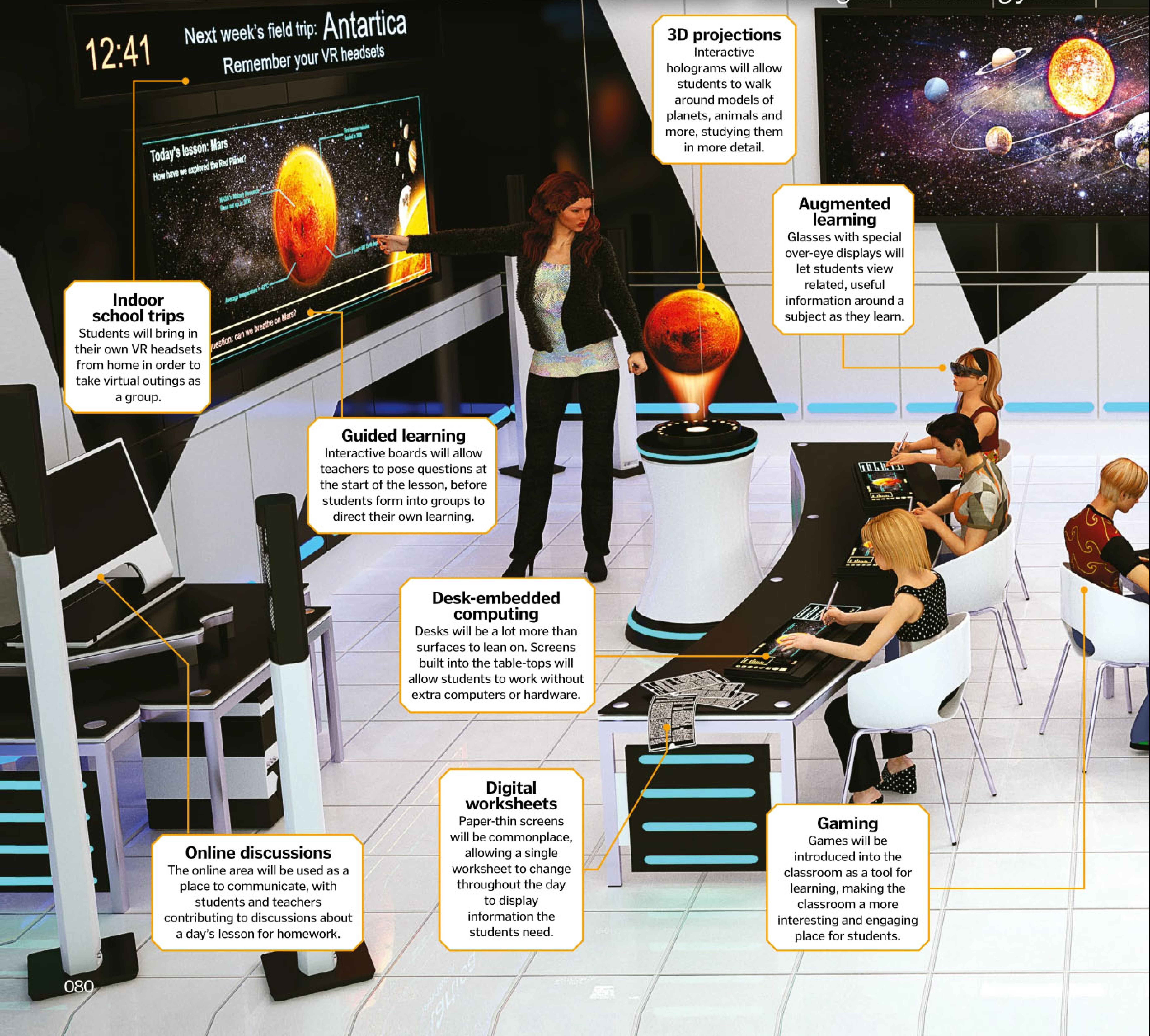


Desk-embedded computing

Augmented learning

FUTURE CLASSROOMS

How will tech change learning in the coming years?


12:41
Next week's field trip: Antartica
Remember your VR headsets
Today's lesson: Mars
How have we explored the Red Planet?
uestion: can we breathe on Mars?

Indoor school trips
Students will bring in their own VR headsets from home in order to take virtual outings as a group.

Guided learning
Interactive boards will allow teachers to pose questions at the start of the lesson, before students form into groups to direct their own learning.

3D projections
Interactive holograms will allow students to walk around models of planets, animals and more, studying them in more detail.

Augmented learning
Glasses with special over-eye displays will let students view related, useful information around a subject as they learn.

Desk-embedded computing
Desks will be a lot more than surfaces to lean on. Screens built into the table-tops will allow students to work without extra computers or hardware.

Online discussions
The online area will be used as a place to communicate, with students and teachers contributing to discussions about a day's lesson for homework.

Digital worksheets
Paper-thin screens will be commonplace, allowing a single worksheet to change throughout the day to display information the students need.

Gaming
Games will be introduced into the classroom as a tool for learning, making the classroom a more interesting and engaging place for students.

DID YOU KNOW? Currently, 3D printers can take hours to print small models, but in future models will be created in minutes

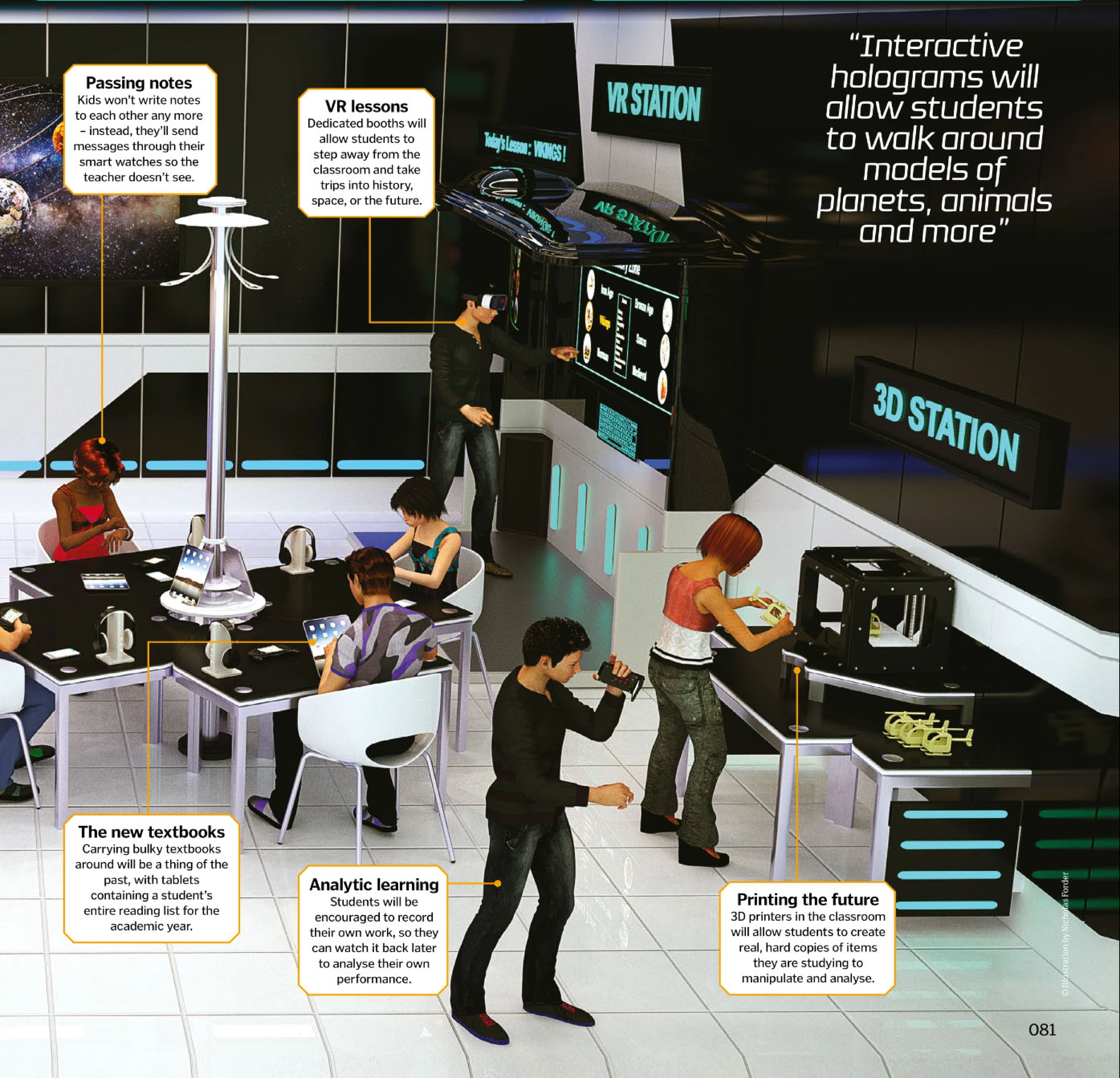
Have you done the Mars quiz yet? 😊

Yeah, it was ok! What did you put for question 3?

I thought there were 4 missions? Or did one get cancelled

Talk later, teacher's watching... 😉

“Interactive holograms will allow students to walk around models of planets, animals and more”



Passing notes
Kids won't write notes to each other any more – instead, they'll send messages through their smart watches so the teacher doesn't see.

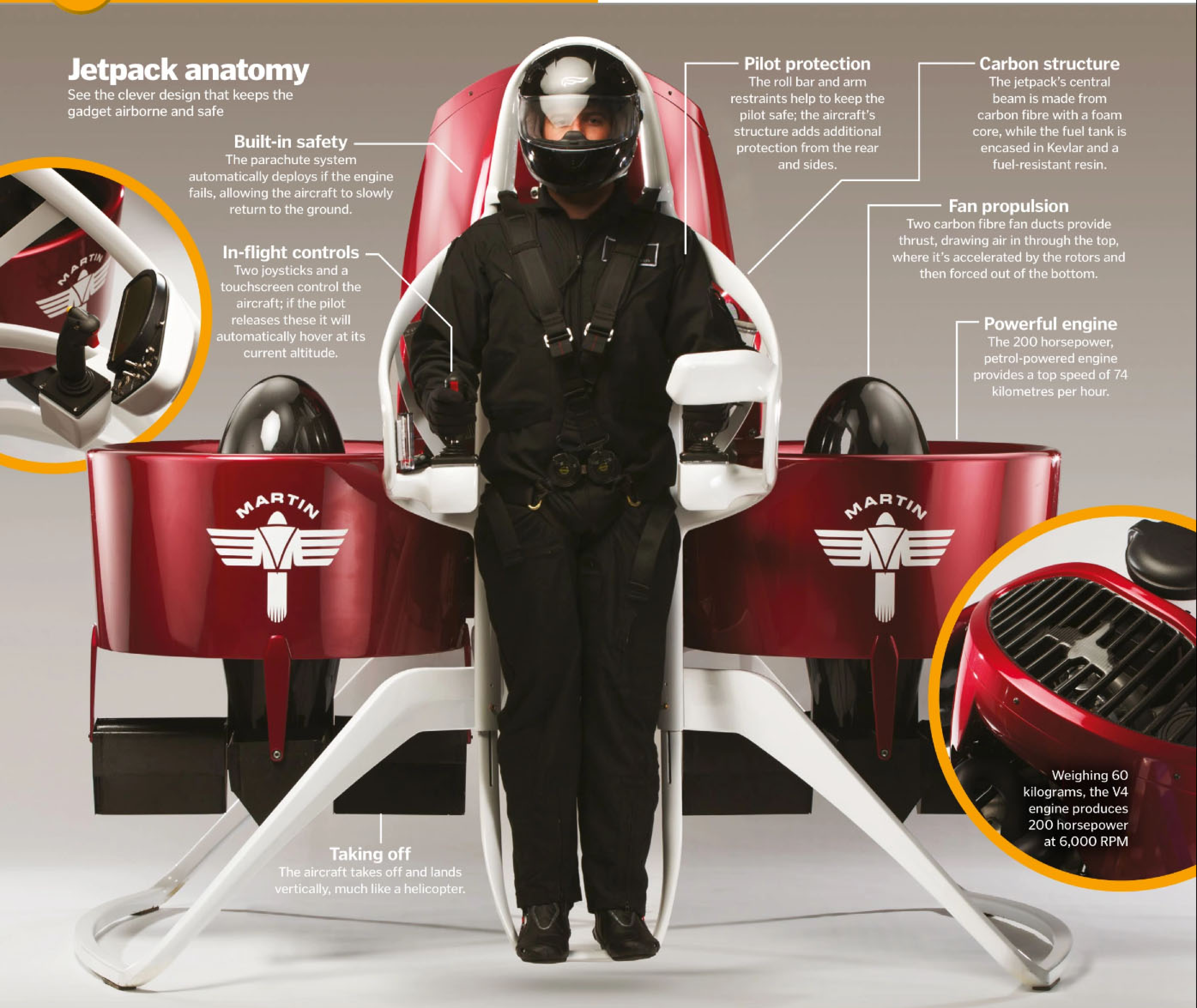
VR lessons
Dedicated booths will allow students to step away from the classroom and take trips into history, space, or the future.

The new textbooks
Carrying bulky textbooks around will be a thing of the past, with tablets containing a student's entire reading list for the academic year.

Analytic learning
Students will be encouraged to record their own work, so they can watch it back later to analyse their own performance.

Printing the future
3D printers in the classroom will allow students to create real, hard copies of items they are studying to manipulate and analyse.

© Illustration by Nicholas Forder



Jetpack anatomy

See the clever design that keeps the gadget airborne and safe

Built-in safety
The parachute system automatically deploys if the engine fails, allowing the aircraft to slowly return to the ground.

In-flight controls
Two joysticks and a touchscreen control the aircraft; if the pilot releases these it will automatically hover at its current altitude.

Pilot protection
The roll bar and arm restraints help to keep the pilot safe; the aircraft's structure adds additional protection from the rear and sides.

Carbon structure
The jetpack's central beam is made from carbon fibre with a foam core, while the fuel tank is encased in Kevlar and a fuel-resistant resin.

Fan propulsion
Two carbon fibre fan ducts provide thrust, drawing air in through the top, where it's accelerated by the rotors and then forced out of the bottom.

Powerful engine
The 200 horsepower, petrol-powered engine provides a top speed of 74 kilometres per hour.

Weighing 60 kilograms, the V4 engine produces 200 horsepower at 6,000 RPM

Taking off
The aircraft takes off and lands vertically, much like a helicopter.

THE MARTIN JETPACK

How does this high-flying gadget take to the skies?

Ever since they first made an appearance in science fiction films, real jetpacks have been promised by a number of different companies and inventors around the world. With its latest prototype, the Martin Aircraft Company believes it has mastered this long anticipated personal aircraft.

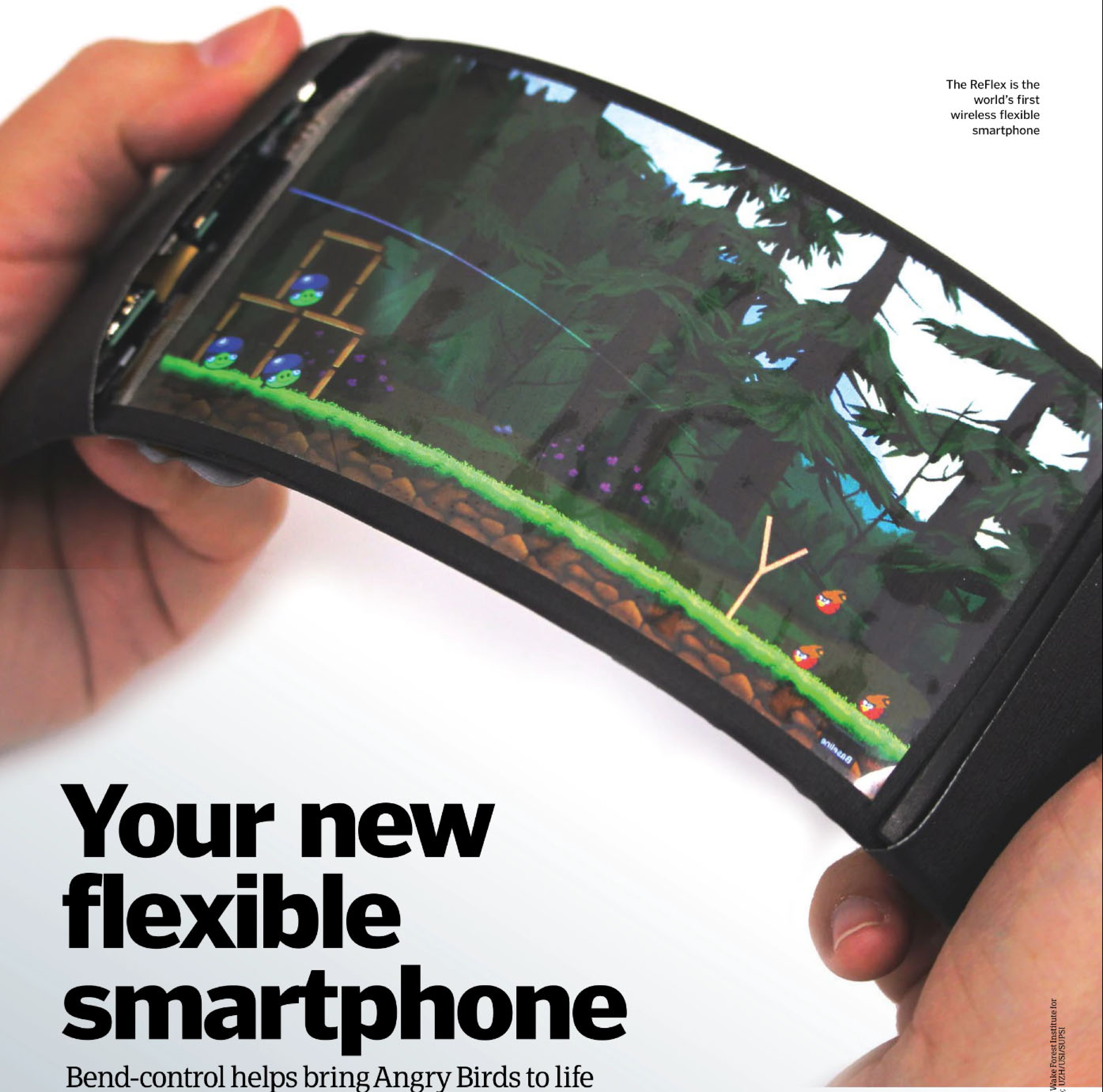
Despite the name, it isn't actually powered by a jet engine. Instead, this contraption relies on a 200 horsepower, V4 engine, fuelled by a mix of regular petrol and two stroke oil – much like old mopeds. This powers two carbon fibre fan ducts, one fitted to either side of the jetpack. Air is drawn in from above and accelerated using the fan's rotors, creating enough downforce to propel a payload of up to 120 kilograms to a height of around 900 metres.

The aircraft is made from sturdy, foam-filled carbon fibre, and can be piloted using two joysticks and a touchscreen, or flown from the ground via a remote control. It benefits from a fly-by-wire, semi-automatic system that helps to balance out the controls between the pilot and the onboard computer. Once airborne, the Martin Jetpack can fly for roughly 30 minutes, achieving a top speed of 74 kilometres per hour.

When this jetpack does eventually go on sale, it will retail in the region of £99,000 ($150,000). However, this won't just be reserved for gadget-loving millionaires. A number of emergency services are interested in using the jetpack; the Abu Dhabi fire service has already made a bulk order.

© Martin Aircraft Company

DID YOU KNOW? *Samsung previously revealed a prototype for a flexible 105 inch TV screen in 2014*



The ReFlex is the world's first wireless flexible smartphone

Your new flexible smartphone

Bend-control helps bring Angry Birds to life

Do you ever wish you could just take your bulky, rigid smartphone and roll it up to put it in your chest pocket? While it might sounds like science fiction, flexible and bendable smartphones are closer than you think – in fact, the technology already exists. When using the world's first wireless flexible smartphone, you can interact with apps simply by bending the handset, as seen in the screen that LG showcased at the Consumer Electronics Show in 2016. So how does it work? Bend sensors behind the LG Display Flexible OLED touch screen sense the force you apply, and this information can be used to flick through the pages of an e-book, or stretch the sling when playing *Angry Birds*. A voice coil inside the phone will then simulate the feedback from these actions through vibrations, helping you feel the rubber band stretch and snap back or the pages flip through your fingers. Your next LG smartphone could well be flexible!

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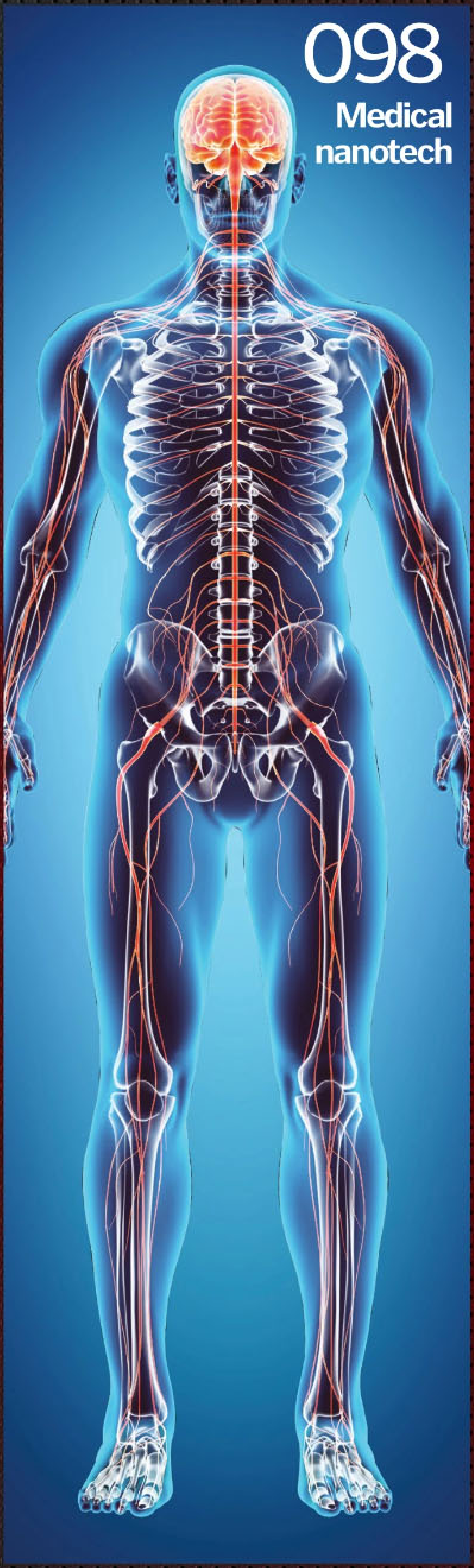
MEDICINE



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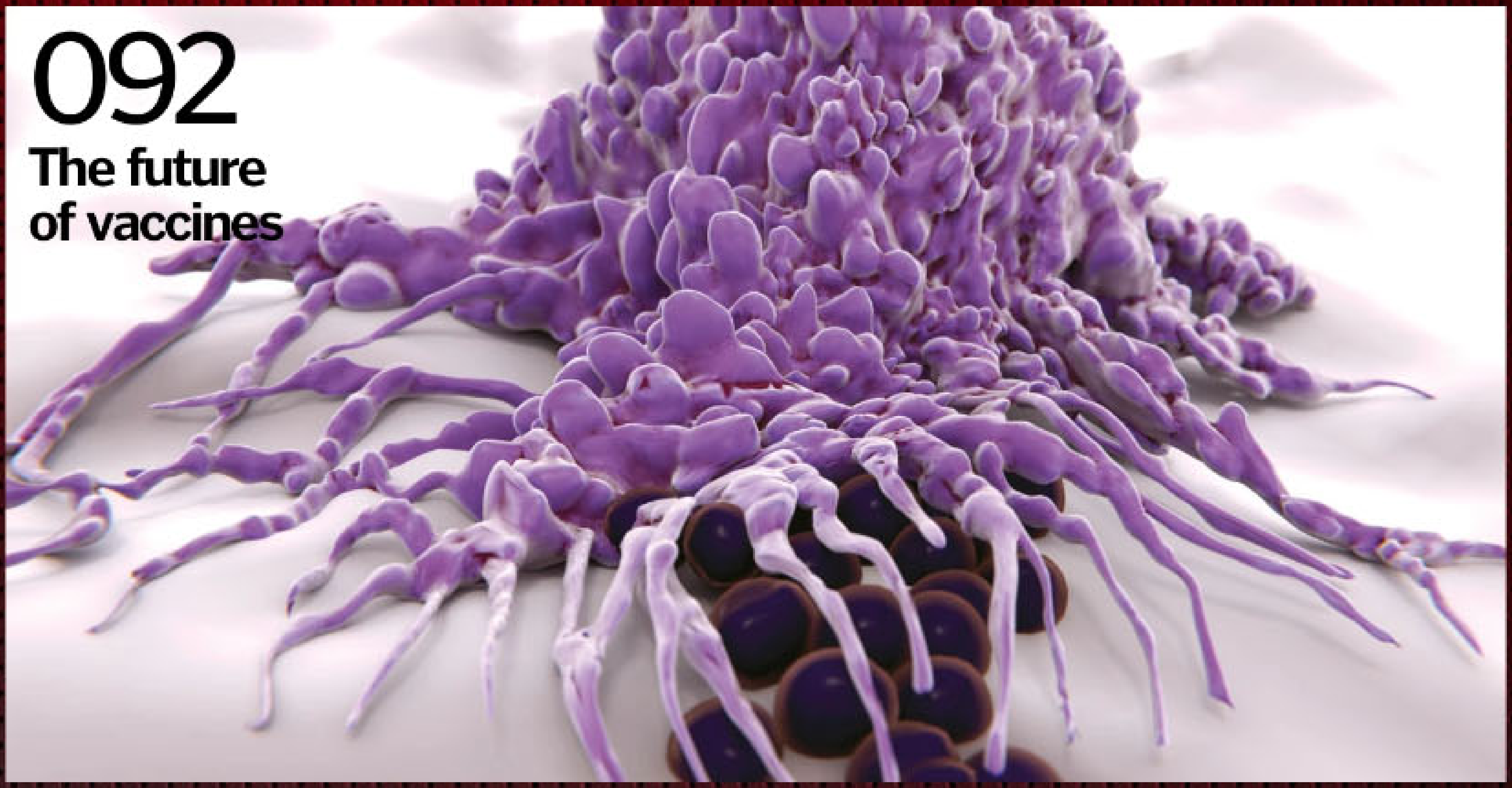
Hacking the body



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How can technology complement our biology?

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Can we predict how fatal diseases might be cured?

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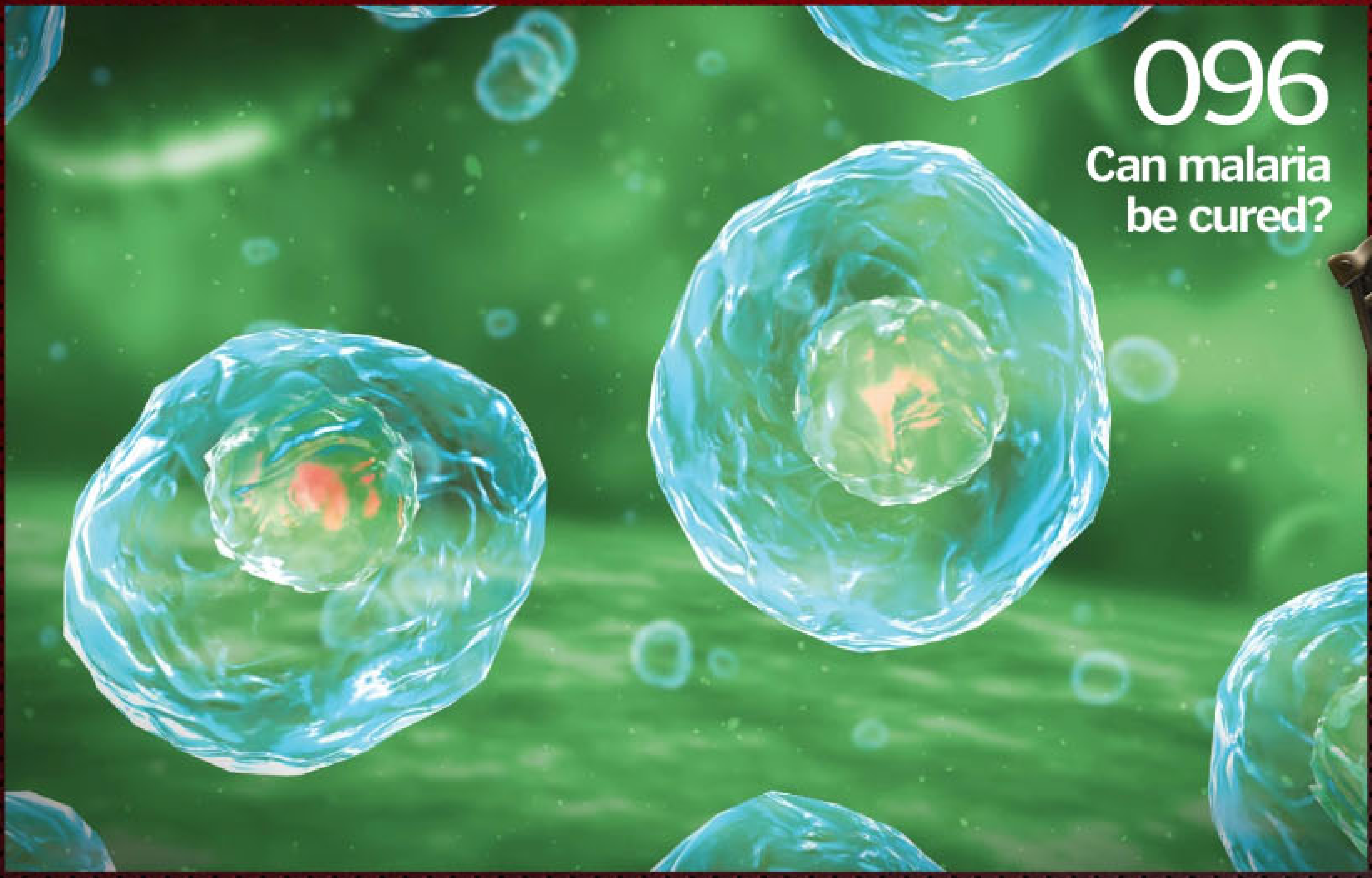
How understanding cancer will help us to treat it



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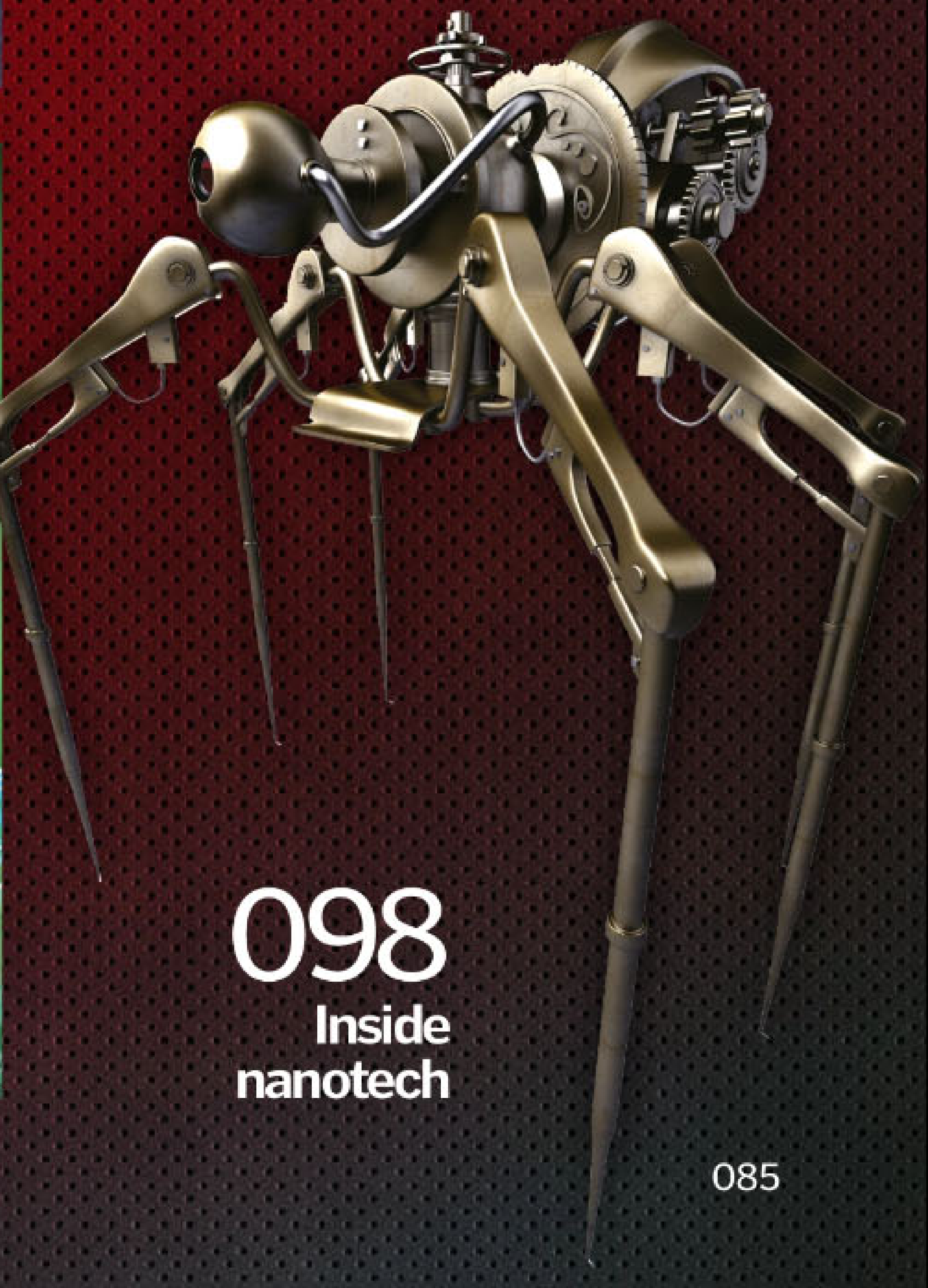
Can malaria be cured?



098
Inside nanotech

HACKING THE HUMAN BODY

YOUR BODY IS YOUR MOST VERSATILE TOOL, BUT WHAT IF YOU COULD IMPROVE IT?

DID YOU KNOW? *Hobbyists who experiment with augmenting their bodies are known as 'biohackers' or 'grinders'*

We are limited by our biology: prone to illness, doomed to wear out over time, and restricted to the senses and abilities that nature has crafted for us over millions of years of evolution. But not any more.

Biological techniques are getting cheaper and more powerful, electronics are getting smaller, and our understanding of the human body is growing. Pacemakers already keep our hearts beating, hormonal implants control our fertility, and smart glasses augment our vision. We are teetering on the edge of the era of humanity 2.0, and some enterprising individuals have already made the leap to the other side.

While much of the technology developed so far has had a medical application, people are now choosing to augment their healthy bodies to extend and enhance their natural abilities.

Kevin Warwick, a professor of cybernetics at Coventry University, claims to be the "world's first cyborg". In 1998, he had a silicon chip implanted into his arm, which allowed him to open doors, turn on lights and activate computers without even touching them. In 2002, the system was upgraded to communicate with his nervous system; 100 electrodes were linked up to his median nerve.

Through this new implant, he could control a wheelchair, move a bionic arm and, with the help of a matched implant fitted into his wife, he was even able to receive nerve impulses from another human being.

Professor Warwick's augmentations were the product of a biomedical research project, but waiting for these kinds of modifications to hit the mainstream is proving too much for some enterprising individuals, and hobbyists are starting to experiment for themselves.

Amal Graafstra is based in the US, and is a double implantee. He has a Radio Frequency Identification (RFID) chip embedded in each hand: the left opens his front door and starts his motorbike, and the right stores data uploaded from his mobile phone. Others have had magnets fitted inside their fingers, allowing them to sense magnetic fields, and some are experimenting with aesthetic implants, putting silicon shapes and lights beneath their skin. Meanwhile, researchers are busy developing the next generation of high-tech equipment to upgrade the body still further.

This article comes with a health warning: we don't want you to try this at home. But it's an exciting glimpse into some of the emerging technology that could be used to augment our bodies in the future. Let's dive in to the sometimes shady world of biohacking.

> "We are teetering on the edge of the era of humanity 2.0"

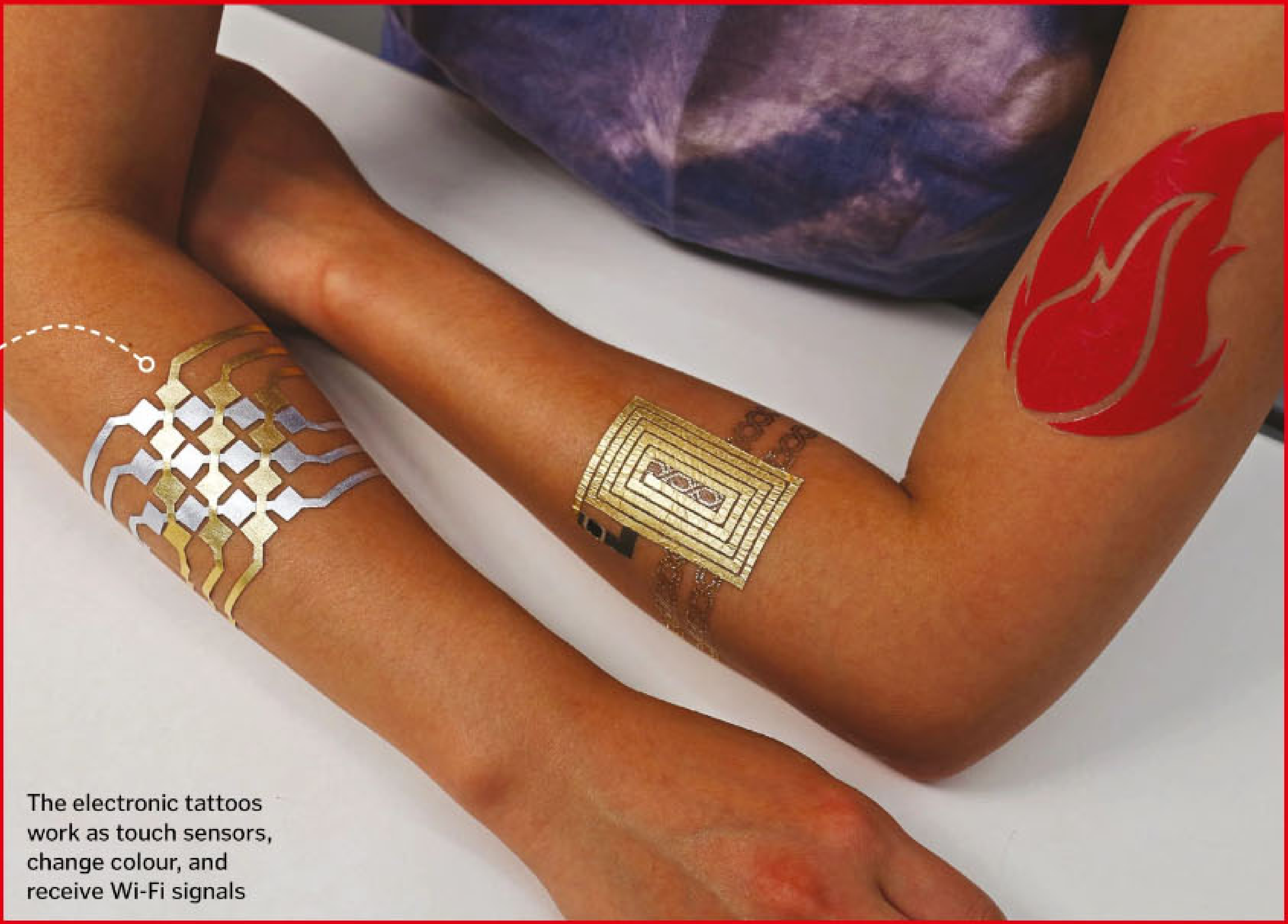
IMPLANTS

Professional and amateur biohackers are exploring different ways of augmenting our skin

Electronic tattoos

Not so much an implant as a stick-on mod, this high-tech tattoo from the Massachusetts Institute of Technology (MIT) can store information, change colour, and even control your phone.

Created by the MIT Media Lab and Microsoft Research, DuoSkin is a step forward from the micro-devices that fit in clothes, watches and other wearables. These tattoos use gold leaf to conduct electricity against the skin, performing three main functions: input, output and communication. Some of the tattoos work like buttons or touch pads. Others change colour using resistors and temperature-sensitive chemicals, and some contain coils that can be used for wireless communication.



The electronic tattoos work as touch sensors, change colour, and receive Wi-Fi signals

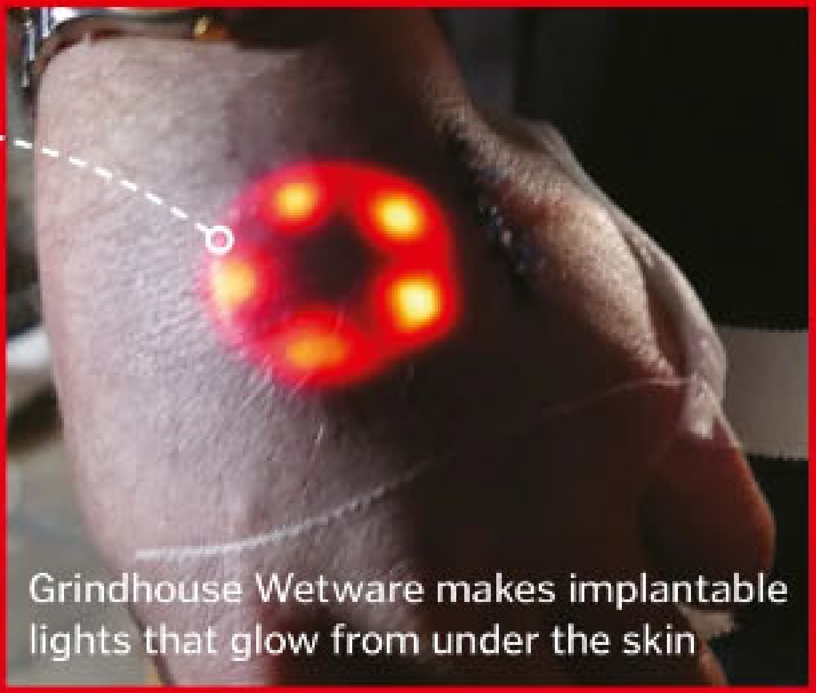
Fingertip magnets

Tiny neodymium magnets can be coated in silicon and implanted into the fingertips. They respond to magnetic fields produced by electrical wires, whirring fans and other tech. This gives the wearer a 'sixth sense', allowing them to pick up on the shape and strength of invisible fields in the air.

The implants allow the wearer to pick up small magnetic objects

Under-skin lights

Some implants are inserted under the skin to augment the appearance of the body. The procedure involves cutting and stitching, and is often performed by tattoo artists or body piercers. The latest version, created by a group in Pittsburgh, even contains LED lights. This isn't for the faint of heart – anaesthetics require a license, so fitting these is usually done without.

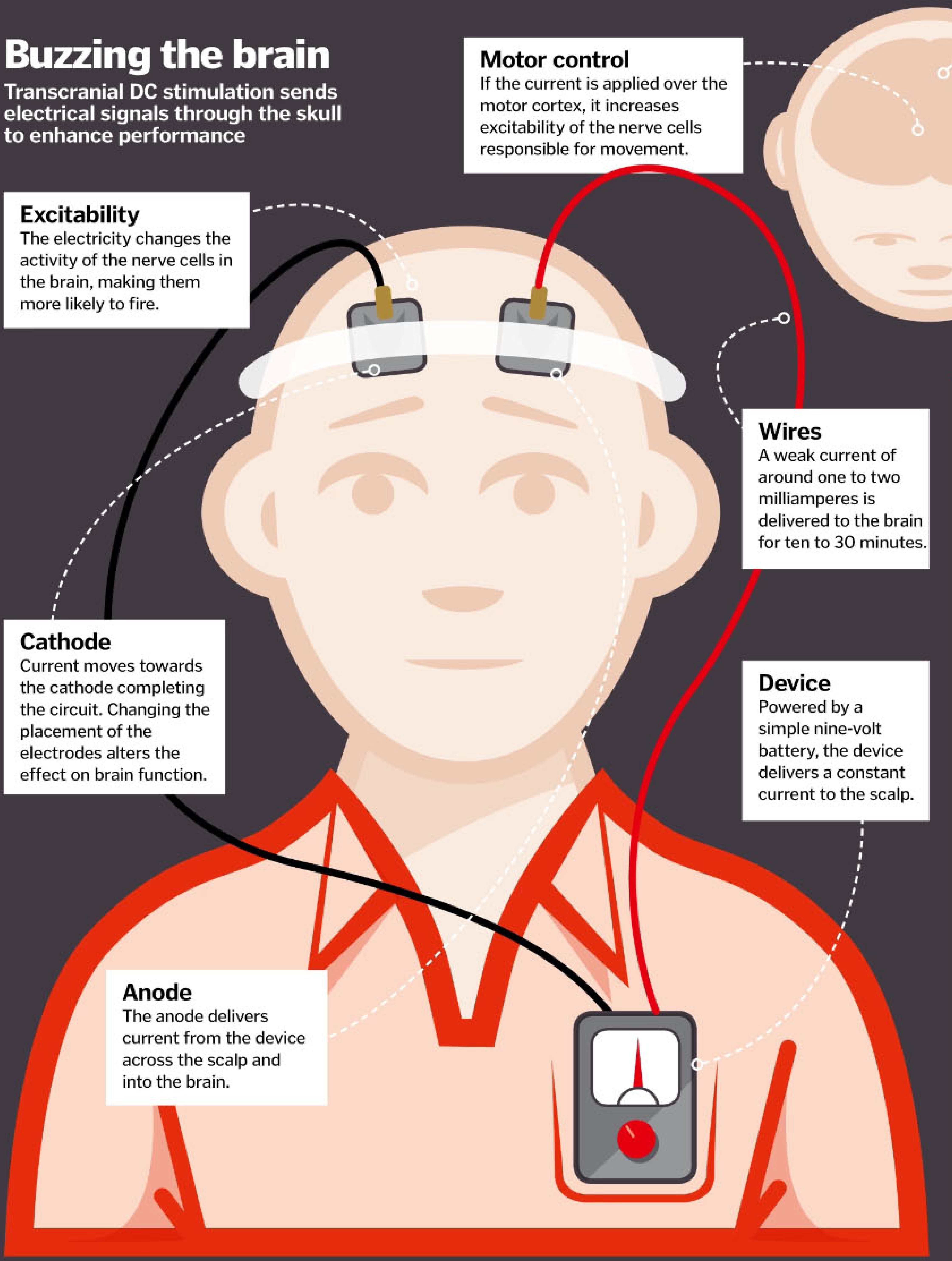


Grindhouse Wetware makes implantable lights that glow from under the skin

© Thinkstock; Alamy; WIKI

Buzzing the brain

Transcranial DC stimulation sends electrical signals through the skull to enhance performance



Motor control
If the current is applied over the motor cortex, it increases excitability of the nerve cells responsible for movement.

Visual perception
Visual information is processed at the back of the brain, and electrodes placed here can augment our ability to interpret our surroundings.

Excitability
The electricity changes the activity of the nerve cells in the brain, making them more likely to fire.

Working memory
Stimulation of the front of the brain seems to improve short-term memory and learning.

Wires
A weak current of around one to two milliamperes is delivered to the brain for ten to 30 minutes.

Cathode
Current moves towards the cathode completing the circuit. Changing the placement of the electrodes alters the effect on brain function.

Device
Powered by a simple nine-volt battery, the device delivers a constant current to the scalp.

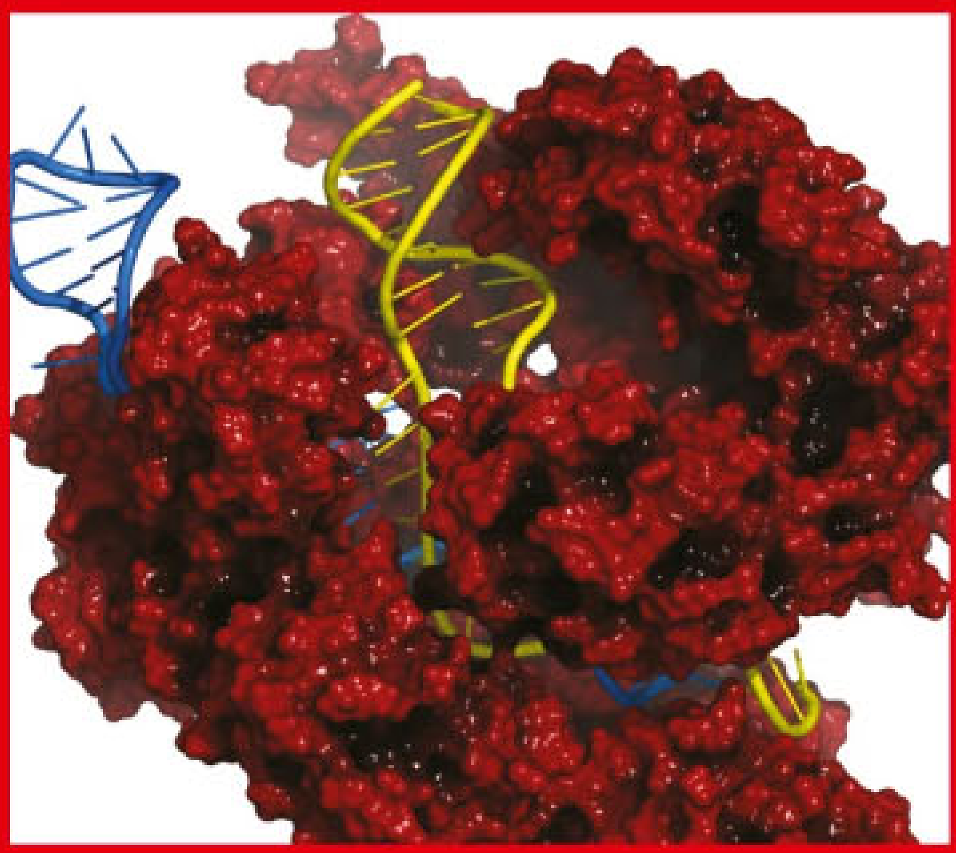
Anode
The anode delivers current from the device across the scalp and into the brain.

Gene editing

In 2013, researchers working in gene editing made a breakthrough. They used a new technique to cut the human genome at sites of their choosing, opening the floodgates for customising and modifying our genetics.

The system that they used is called CRISPR. It is adapted from a system found naturally in bacteria, and is composed of two parts: a Cas9 enzyme that acts like a pair of molecular scissors, and a guide molecule that takes the scissors to a specific section of DNA.

What scientists have done more recently is to hijack this system. By 'breaking' the enzyme scissors, the CRISPR system no longer cuts the DNA. Instead, it can be used to switch the genes on and off at will, without changing the DNA sequence. At the moment, the technique is still experimental, but in the future it could be used to repair or alter our genes.



The CRISPR complex works like a pair of DNA-snipping scissors

HACKING THE BRAIN

With the latest technology we can decipher what the brain is thinking, and we can talk back

The human brain is the most complex structure in the known universe, but ultimately it communicates using electrical signals, and the latest tech can tap into these coded messages.

Prosthetic limbs can now be controlled by the mind; some use implants attached to the surface of the brain, while others use caps to detect electrical activity passing across the scalp. Decoding signals requires a lot of training, and it's not perfect, but year after year it is improving.

It is also possible to communicate in the other direction, sending electrical signals into the brain. Retinal implants pick up light, code it into electrical pulses and deliver them to the optic nerve, and cochlear implants do the same with sound in the ears via the cochlear nerve. And, by attaching electrodes to the scalp, whole areas of the brain can be tweaked from outside.

Transcranial direct current stimulation uses the weak currents that pass through the skin and bone to the underlying brain cells. Though this is still in development, early tests have indicated that this can have positive effects on your mood, memory and other brain functions. The technology is relatively simple, and there are some companies that are already offering the kit to people at home. It's even possible for you to make one yourself.

However, the researchers of this technology are urging caution. They admit that they still aren't exactly sure how it works, and messing around with your brain could have very dangerous consequences.

> "Prosthetic limbs can now be controlled by the mind"

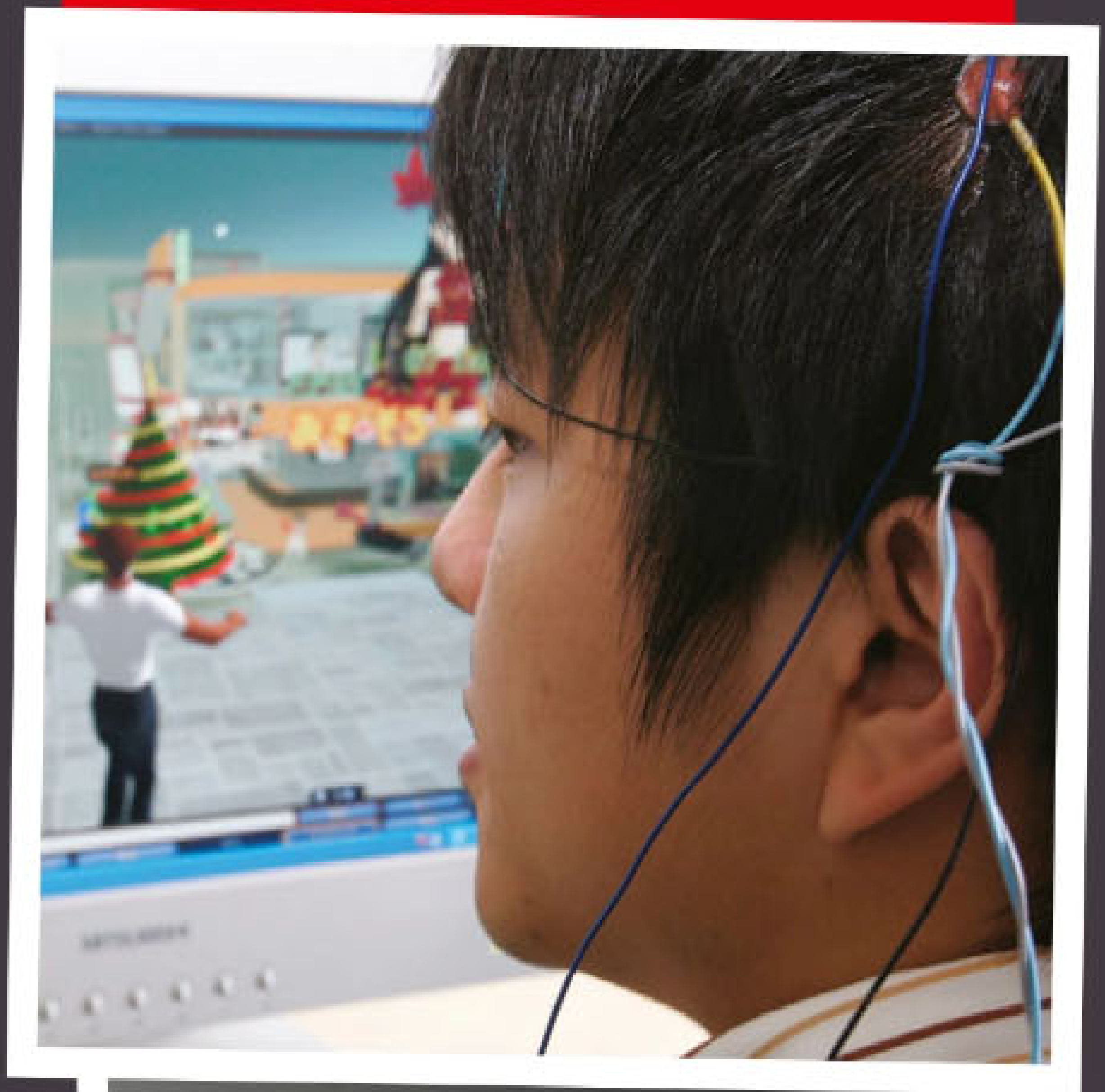
DID YOU KNOW? *Neil Harbisson is a colour-blind artist with an implanted antenna that turns colour into sound*

Exoskeletons and virtual reality

At the 2014 World Cup in Brazil, Miguel Nicolelis from Duke University teamed up with 29-year-old Juliano Pinto to showcase exciting new technology. Pinto is paralysed from the chest down, but with the help of Nicolelis' mind-controlled exoskeleton and a cap to pick up his brainwaves, he was able to stand and kick the official ball.

The next step in Nicolelis' research has been focused on retraining the brain to move the legs – and this time he's using VR. After months of controlling the walking of a virtual avatar with their minds, eight people with spinal-cord injuries have actually regained some movement and feeling in their own limbs.

Electrodes can pick up neural impulses, so paralysed patients are able to control virtual characters with their brain activity



Exosuits can amplify your natural movement, while some models can even be controlled by your mind

COMMUNITY BIOLOGY LABS

We spoke to Tom Hodder, technical director at London Biological Laboratories Ltd to learn more about public labs and the biohacking movement

Interview bio:
Tom Hodder studied medicinal chemistry and is a biohacker working on open hardware at London Biohackspace.

What is the London Biohackspace?
The London Biohackspace is a biolab at the London Hackspace on Hackney Road. The lab is run by its members, who pay a small monthly fee. In return they can use the facilities for their own experiments and can take advantage of the shared equipment and resources. In general the experiments are some type of microbiology, molecular or synthetic biology, as well as building and repairing biotech hardware.

Who can get involved? Is the lab open to anyone?
Anyone can join up. Use of the lab is subject to a safety induction. There is a weekly meet-up on Wednesdays at 7.30pm, which is open to the public.

Why do you think there is such an interest in biohacking?
Generally, I think that many important problems, such as food, human health, sustainable resources (e.g. biofuels) can be potentially mitigated by greater understanding of the underlying processes at the molecular biological level. I think that the biohacking community is orientated towards the sharing of these skills and knowledge in an accessible way. Academic research is published, but research papers are not the easiest reading, and the details of commercial research are generally not shared unless it's patented. More recently, much of the technology required to perform these experiments is becoming cheaper and more accessible, so it is becoming practical for biohacking groups to do more interesting experiments.

Where do you see biohacking going in the future?
I think in the short term, the biohacking groups are not yet at an equivalent level to technology and resources to the universities and commercial research institutions. However in the next five years, I expect more open biolabs and biomakerspaces to be set up and the level of sophistication to increase.
I think that biohacking groups will continue to perform the service of communicating the potential of synthetic and molecular biology to the general public, and hopefully do that in an interesting way.

Community labs are popping up all over the world, providing amateur scientists with access to biotech equipment

© Thinkstock; Alamy; Ekso Bionics

BUILDING FUTURE YOU

A closer look at some of the emerging tech that will allow you to customise your body

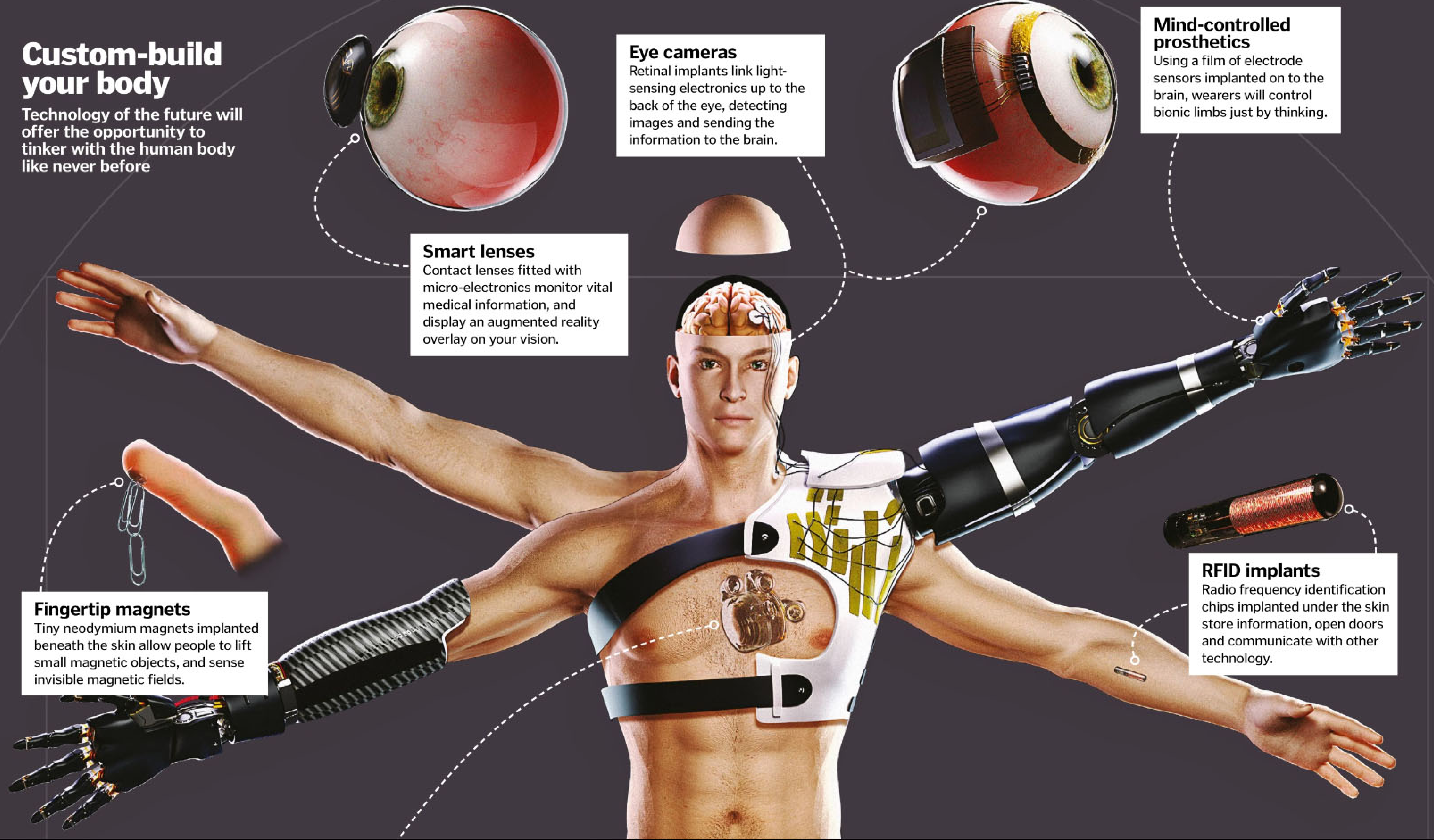
Self-improvement is part of human nature, and technology is bringing unprecedented possibilities into reach. Much of the development up until this point has had a medical purpose in mind, including prosthetic limbs for amputees, exoskeletons for paralysis, organs for transplant, and light sensors for the blind. However, with the advent of wearable technology, and a growing community of amateur and professional biotechnology tinkerers, there is increased interest in augmenting the healthy human body.

The first cyborgs already walk among us, fitted with magnetic senses, implanted with microchips, and talking to technology using their nervous systems. At the moment, many devices are experimental, sometimes even homemade and unlicensed. However, the field is opening up, and the possibilities are endless.

So, what does the future hold for a customisable you? Medical implants could monitor, strengthen, heal or replace our organs. We could add extra senses, or improve the ones we already have. And, one day, we might be able to tap straight into the internet with our minds.

Custom-build your body

Technology of the future will offer the opportunity to tinker with the human body like never before



Smart lenses
Contact lenses fitted with micro-electronics monitor vital medical information, and display an augmented reality overlay on your vision.

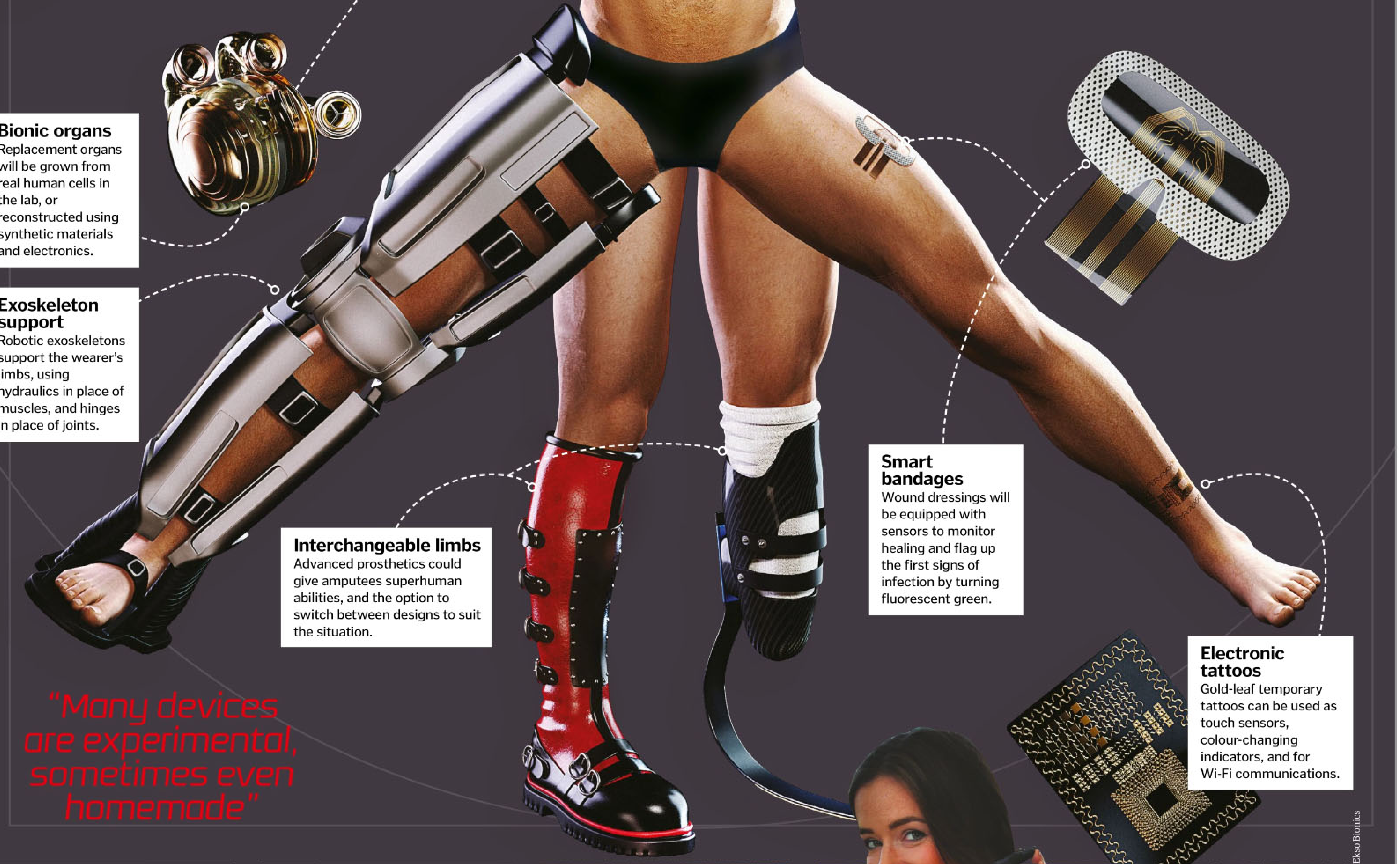
Eye cameras
Retinal implants link light-sensing electronics up to the back of the eye, detecting images and sending the information to the brain.

Mind-controlled prosthetics
Using a film of electrode sensors implanted on to the brain, wearers will control bionic limbs just by thinking.

Fingertip magnets
Tiny neodymium magnets implanted beneath the skin allow people to lift small magnetic objects, and sense invisible magnetic fields.

RFID implants
Radio frequency identification chips implanted under the skin store information, open doors and communicate with other technology.

DID YOU KNOW? *The oldest prosthetic is a wood and leather toe, found on an Ancient Egyptian mummy from 950-710 BCE*



Bionic organs
Replacement organs will be grown from real human cells in the lab, or reconstructed using synthetic materials and electronics.

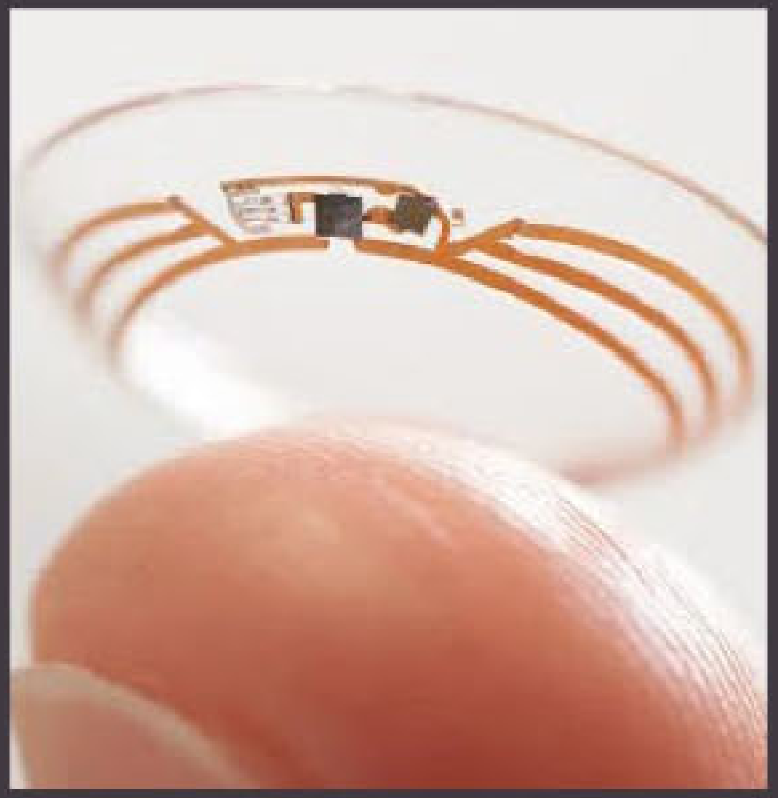
Exoskeleton support
Robotic exoskeletons support the wearer's limbs, using hydraulics in place of muscles, and hinges in place of joints.

Interchangeable limbs
Advanced prosthetics could give amputees superhuman abilities, and the option to switch between designs to suit the situation.

Smart bandages
Wound dressings will be equipped with sensors to monitor healing and flag up the first signs of infection by turning fluorescent green.

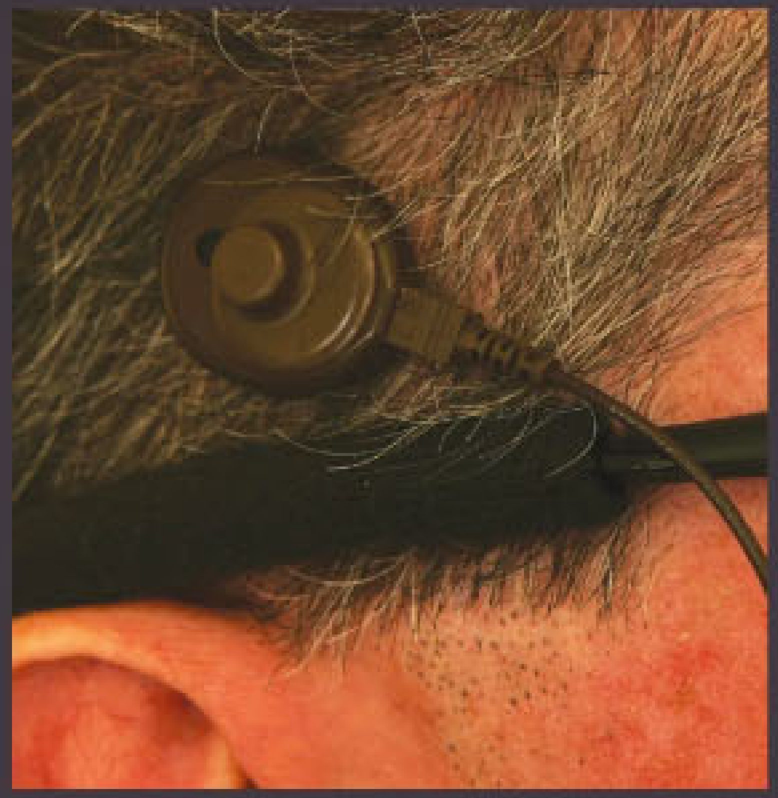
Electronic tattoos
Gold-leaf temporary tattoos can be used as touch sensors, colour-changing indicators, and for Wi-Fi communications.

> "Many devices are experimental, sometimes even homemade"



Google is developing a contact lens that senses blood sugar by analysing tears

This RFID chip shows the coiled copper antenna it uses to communicate



The Argus implant's camera and transmitter signal to the optic nerve

The i-limb hand can be moved by gestures, apps, muscle signals or proximity sensors

Ekso moves legs in response to upper body movement

© Shutterstock; Google; Touch Bionics; Illustration by Nicholas Forder; Ekso Bionics

THE FUTURE OF MEDICINE

How are we going to beat the world's deadliest diseases?

Medical science has produced some incredible solutions to challenging problems over the decades, from antibiotics to fight bacterial infection, to imaging technologies to look inside patients without using a knife. It's hard to predict what will happen next, but science has recently opened some really exciting doors to the future of medical treatment.

Medicine is no longer just about biology and drugs. Computing, engineering, nanotechnology, quantum physics, and many more disciplines are leaking over into medical tech and providing brand new solutions to age-old problems.

In the hospitals of the future, augmented reality could allow surgeons to see through their patients, and contact lenses could monitor blood sugar for diabetics. Prosthetic limbs linked directly to the nervous system could allow amputees to move and feel just by thinking, and 3D printers could be utilised to create custom medical kit, or even fully working replacement organs, on demand.

We are learning how to retrain our own immune systems to fend off deadly diseases, and we are developing technology that could allow our own genetics to be tweaked and changed on the go. The scientific community has access to a massive and rapidly expanding pool of data from patients the world over, and as we dig deeper into the biochemistry of illness, new ways to precisely treat disease are set to appear.

One day, wearable tech and at-home test kits could monitor for the first signs of sickness, and custom treatments might be delivered based on our own unique genetic and biochemical fingerprints, minimising side effects and maximising our chances of recovery.

DID YOU KNOW? *In 2014 scientists grew a whole organ, called a thymus, inside a mouse using stem cells*

How germs spread

Body fluids

Blood, saliva, semen and breast milk can all carry disease

Liquids provide an excellent way for pathogens to travel from one place to another. Precautions are always taken when dealing with body fluids in hospitals and labs, because contaminated body fluids can transmit diseases like mumps, hepatitis and HIV.

Skin to skin contact

Some infections are quickly spread by direct contact

Chickenpox, cold sores, head lice and warts can all be transmitted by touching someone with the infection; the viruses, bacteria, or parasites simply move from one person to another. Some of these examples can also survive on inanimate surfaces for a short time.

Food and drink

Contaminated food and drink carry pathogens into the gut

The acidity of the stomach provides some protection against infection, but it can't stop everything. Pathogens enter through the mouth, and either set up home in the digestive tract, or move into the body through its walls.

Droplets

Pathogens can be transmitted short distances by drops of liquid in the air

Tiny drops of fluid released by a cough or a sneeze travel around a metre before they settle onto door handles, surfaces and skin. It's an easy way for respiratory infections to spread. Examples include colds, flu and rubella.

Preventing history's biggest killers

Vaccinations teach the immune system how to fight, before it encounters the disease

Our natural defence against disease is our immune system. It's an army of cells that work together to patrol the body and destroy anything that shouldn't be there. It's split into two parts, a fast-response 'innate' system, that wages war at the first sign of trouble, and a slow, specialised 'adaptive' system that delivers a stronger and more focused attack.

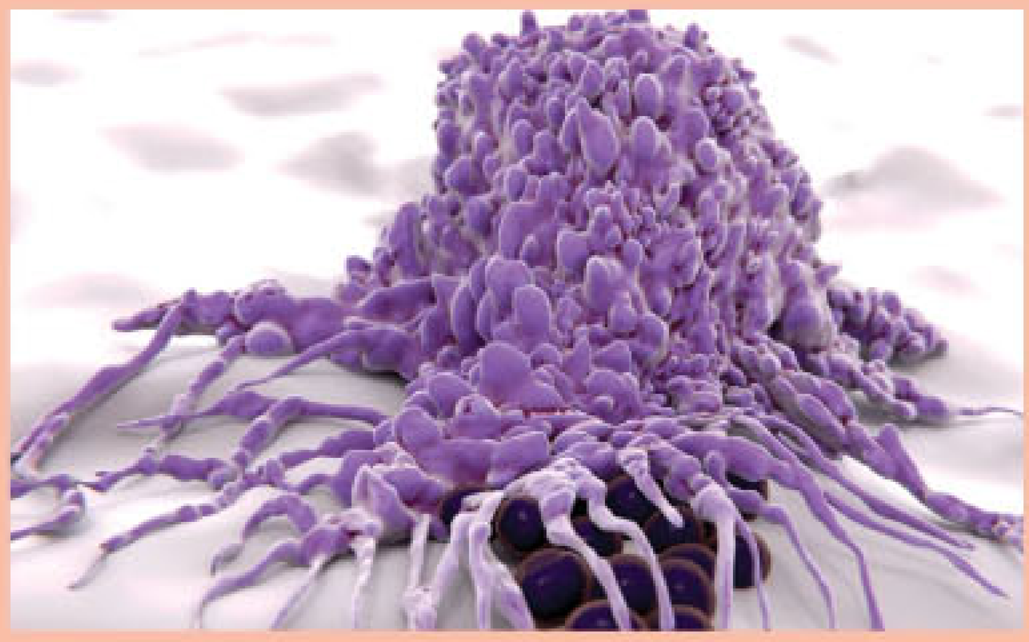
The first time the immune system meets a new infection, it takes up to a week for the specialised immune cells to appear. In this time, the pathogen can multiply, and people can become very sick. Vaccinations bypass this step by giving the immune system a chance to train beforehand.

The first vaccine was developed by Edward Jenner in 1796. He noticed that milkmaids didn't catch smallpox; they were exposed to a similar disease, cowpox, and their immune systems were better trained. Jenner tried infecting children with cowpox, and found that they too gained protection.

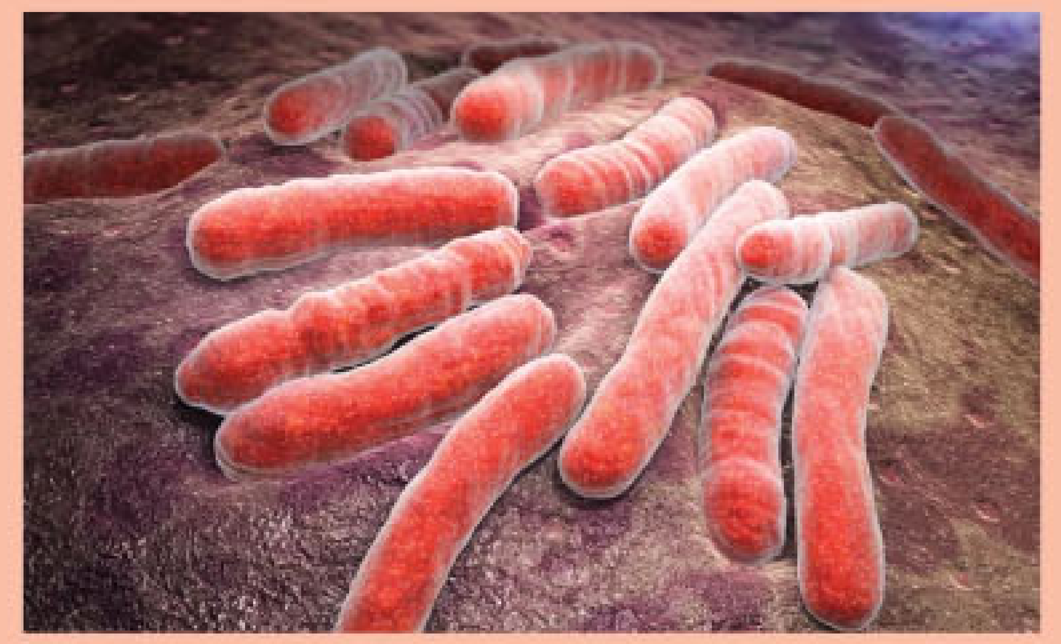
Vaccinations have been developed against dozens of infectious diseases, and they are now being made to teach the immune system to fight other illnesses too.

Training the immune system

Vaccinations are like a training program for your immune system, giving it a sneak peek at enemies that it might encounter in the future so that it can prepare in advance. They can be made in different ways, but usually contain inactive bacteria or viruses, or examples of molecules that the pathogens make.



When the vaccination has been injected, your immune system comes to have a look. It will examine the parts of the pathogen and work out the best way to attack, as though it were fighting the real thing. After the vaccine has been cleared up, some of the cells that fought it remain in the body on patrol as 'memory cells'.



When you encounter the real pathogen, your immune system will be ready to respond. Instead of spending time working out what to do, the memory cells left over from the vaccine instantly clone themselves, producing an army of cells that can clear the infection before you get sick.

© Thinkstock

The end of HIV

How do you hunt down a virus that's hiding in your own immune system?

Human Immunodeficiency Virus (HIV) hijacks the immune system. The virus gets inside, inserts its genetic code into the genome of a cell, and transforms it into a factory to make more of the virus. While this is happening, the cell is unable to function normally, and gradually as more and more cells are taken over, the immune system is left seriously weakened. The result is known as Acquired Immune Deficiency Syndrome (AIDS).

HIV is now treatable with a combination therapy that stops the virus from replicating. The amount of virus often dips so low in the blood that the disease can't be passed on. Transmission from mother to child is also being eliminated with new drugs. However, not everyone has access to treatment.

The gold standard for the future of HIV medicine would be a vaccine that can teach the immune system to neutralise the virus with a coating of antibodies. In theory, this could be used not only to prevent infection, but also to stop the disease coming back in people who have some virus still hiding in their systems.

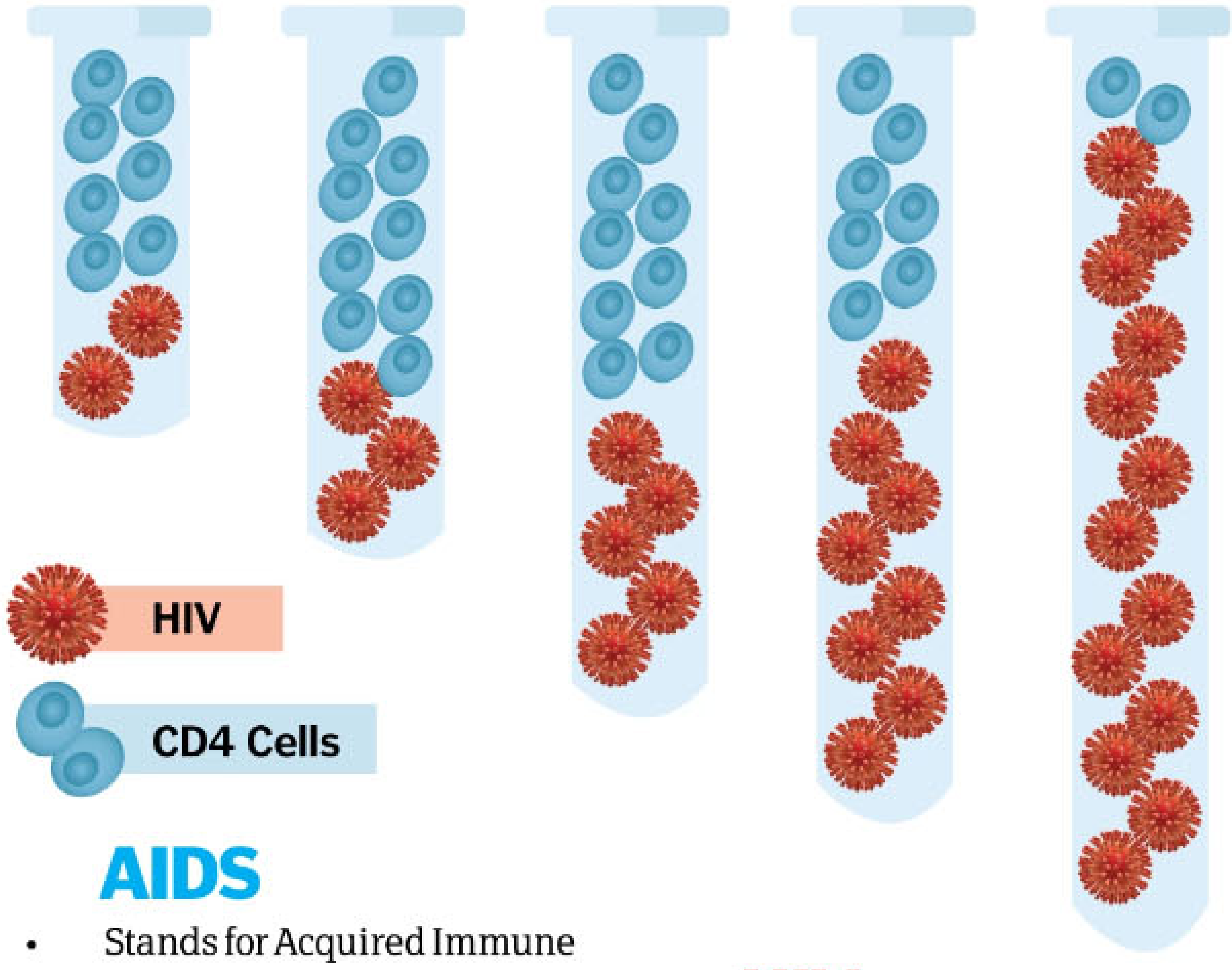
This is a huge challenge; the virus shape-shifts to avoid detection, and the immune system doesn't usually respond. But new vaccines are being trialled all the time, and as our understanding of HIV and the immune system improves, we are inching closer to making it a reality.

How hard is it to cure?

HIV stitches its genome into to the genome of immune cells, so that the two are permanently linked together. Antiretroviral treatment can stop the virus from making copies of itself, but they can't get rid of it completely unless the immune cells themselves are killed.

This has been done once, in 2007. The Berlin Patient had cancer and needed a bone marrow transplant. His own immune system, carrying the HIV, was destroyed, and replaced with donor cells. They had a genetic mutation that made it harder for HIV to infect them, and the patient was cured.

Bone marrow transplants are risky, however, and there aren't enough donors available, so it's not a practical solution to rid the world of HIV altogether.



AIDS

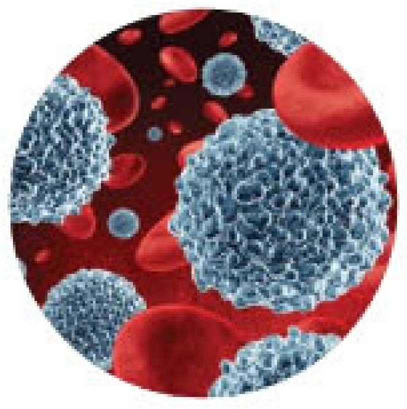
- Stands for Acquired Immune deficiency Syndrome
- Is the disease caused by HIV
- Takes advantage of the damaged immune system that is unable to fight it
- People die due to infection or resulting cancer

HIV

- Stands for Human Immunodeficiency Virus
- Is the virus that causes AIDS
- It infects the immune system
- Infection compromises the cells of the immune system

Timeline

1981
Men in California start to fall ill with unusual infections after their immune systems become weakened.



1983
Scientists discover that human immunodeficiency virus (HIV) is the cause of acquired immune deficiency syndrome (AIDS).

1985
Commercial blood tests for HIV are invented, allowing screening to begin.

1987
The first drug treatment for HIV, azidothymidine, is approved.

1996
Triple-drug therapy is introduced, turning HIV infection into a long-term disease.

2007
A single patient in Berlin is cured by a pioneering bone marrow transplant.

Future
A vaccine is developed to train the immune system to attack HIV.

Future
A drug is developed to reveal HIV lurking in dormant cells.

37 million

In 2015, nearly 37 million people were living with HIV

Over half of people with HIV can't access treatment

1.1 million

people die as a result of AIDS each year

HIV is transmitted through body fluids, including blood, semen and breast milk

8 out of **10** pregnant women with HIV receive treatment to minimise the risk to their child

HIV infects the immune system, crippling the body's defences

40%

of people with HIV don't know they're infected

Antiretroviral therapy stops the virus replicating

Condoms, HIV testing, and circumcision help to reduce transmission

HIV puts people at risk of catching other diseases like tuberculosis

DID YOU KNOW? *The highest death rates for heart disease are in Eastern Europe and Central Asia*

Can cancer be cured?

Huge progress has been made over the past century, but what happens next?

Cancer is an ancient disease; tumours has been found in Egyptian mummies, and even in the fossils of dinosaurs. It happens when genes involved in growth and repair go wrong. Affected cells make copy upon copy of themselves, and these new cells start to break away, travelling around the body and making yet more copies elsewhere.

If cancer is caught early, it can already be cured. If the tumour is removed, the cancer is gone. However, once the cancer has spread it is harder to treat, and the more it spreads, the less likely people are to survive.

Stopping cancer before it really starts would be the best option. Vaccinations might be used to train the immune system to recognise cancer cells, or a routine blood or breath test could be developed to pick up the earliest signs of the disease. However, the likelihood of cancer increases with age, and with people living longer the incidence is rising.

For those who do develop the disease, several futuristic treatment options are already being developed. Future humans could end up having their immune systems retrained and augmented, or they might receive genetically engineered viruses designed specifically to infect and kill the tumour. We might even be able to switch genes on and off inside tumour cells to halt their growth.

The future of cancer medicine

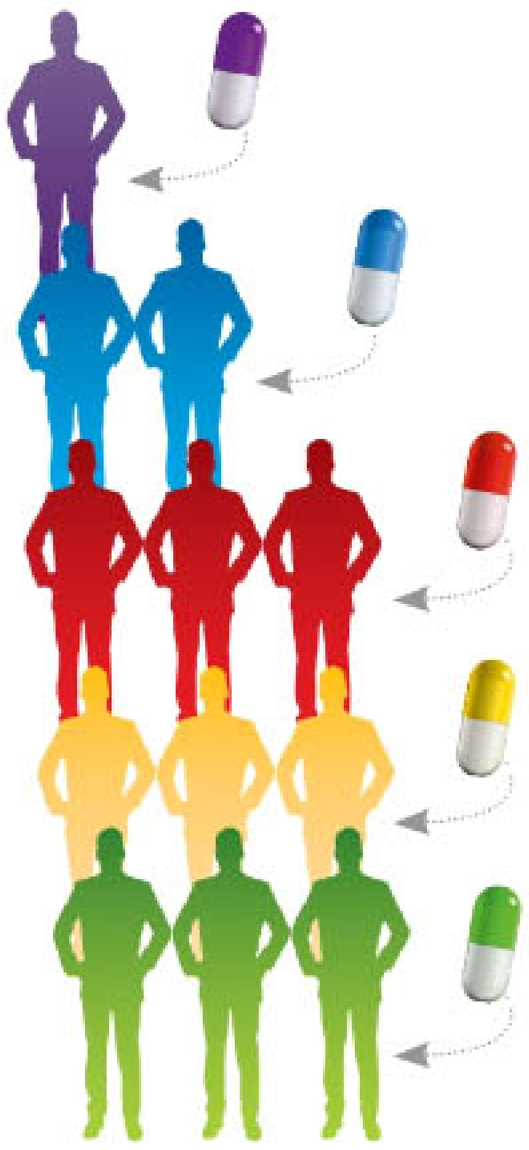
Matching people to the right treatment could be the answer to controlling cancer

Group of patients

Several people might have brain cancer, but not all brain cancers are the same.

Genetic testing

The patients are tested to find out the exact genetic and chemical makeup of their tumour.



Treatment matching

Patients are matched with treatments that specifically target the weaknesses of their own cancer.

Where is the cancer cure?

Cancer gets a lot of research money, and thousands upon thousands of scientists are working to try and find the cure, so where is it? If you can cut the tumour out before it has a chance to spread, you can cure it, but if any cells have escaped they need to be found. Radiotherapy and chemotherapy can help to mop up stragglers, but they don't always work, and some cancer cells develop ways to avoid them. The big challenge is that everyone is different, and so too are everyone's cancers. And tumours don't just differ between people, they also change over time. The challenge is to find out how they change, and how these different weaknesses can be targeted with treatments.

Timeline

1846
The invention of general anaesthetic paves the way for surgery to finally remove tumours.

1880s
The first mastectomy is performed, finally providing treatment for breast cancer.

1903
Radium is used to treat skin cancer, the in what is the first example of radiotherapy.

1949
The first chemotherapy drug is approved. It is nitrogen mustard, a WWII weapon.

1950s
Smoking is finally shown to cause lung cancer, encouraging millions to give up.

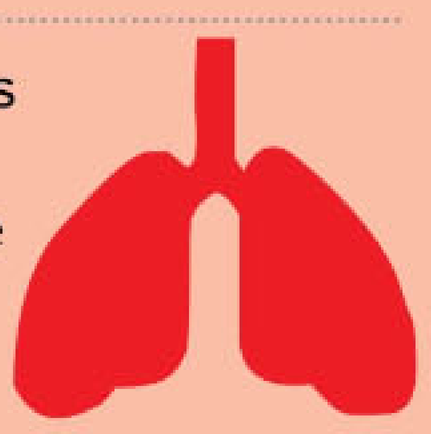
1990s
Cancer mortality starts to drop in developed countries as diagnoses and treatment improve.

Future
Personalised medicine becomes reality, with patients matched to treatments based on their genes.

Future
A simple blood test is developed to pick up the very earliest signs of cancer.

14 million people are diagnosed with cancer each year

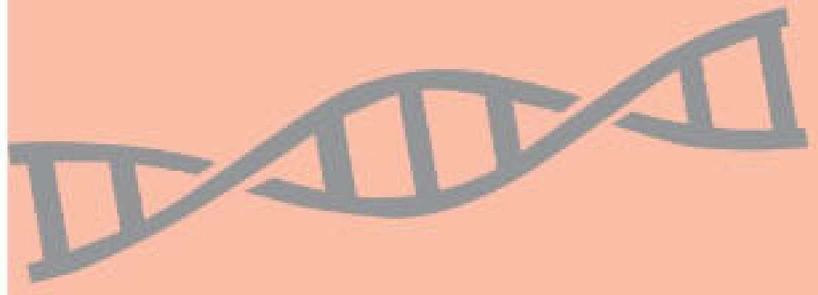
8 million people die of cancer each year



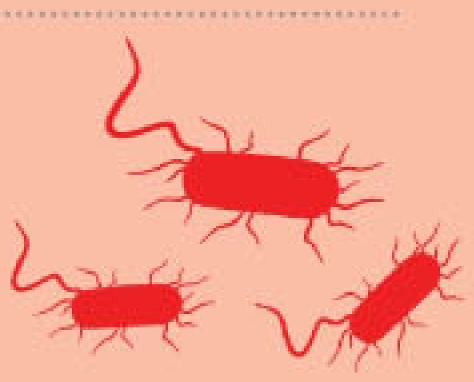
Lung cancer is the most common type of cancer in men

Breast cancer is the most common type of cancer in women

The older you are, the more likely you are to get cancer



Cancer is not contagious, but it can be genetic



Viral infections can cause some cancers

The earlier cancer is detected, the easier it is to treat

Lifestyle changes could prevent a third of cancers

Eliminating malaria

This deadly disease is carried by mosquitoes, but work is being done around the world to wipe it out

Just one mosquito bite is enough to kill you in some parts of the world. Inside the midgut of Anopheles mosquitoes, gametocytes from the plasmodium parasite mature and combine. These are the equivalent of human sperm and eggs, and the result is hundreds of newly formed parasites ready to infect their next victim.

The parasites migrate up to the mosquito's salivary glands, and when it feeds again they enter the human bloodstream. They infect cells in the liver and begin to divide, before spreading back into the blood. As they continue to grow, the cells split open, releasing even more parasites and causing havoc for the body.

Malaria parasites can't reproduce without both mosquitoes and humans, giving us a tantalising opportunity to eliminate them. One idea is to genetically modify colonies of mosquitoes and release them to breed with their wild counterparts; this could be used to introduce damaging genetic traits into the population, either killing the parasites, or killing the mosquitoes themselves. Another option is to develop fungi that can infect and kill the insects.

Other options for elimination include designing new insecticides to keep insect numbers down, and developing a vaccine to halt transmission.

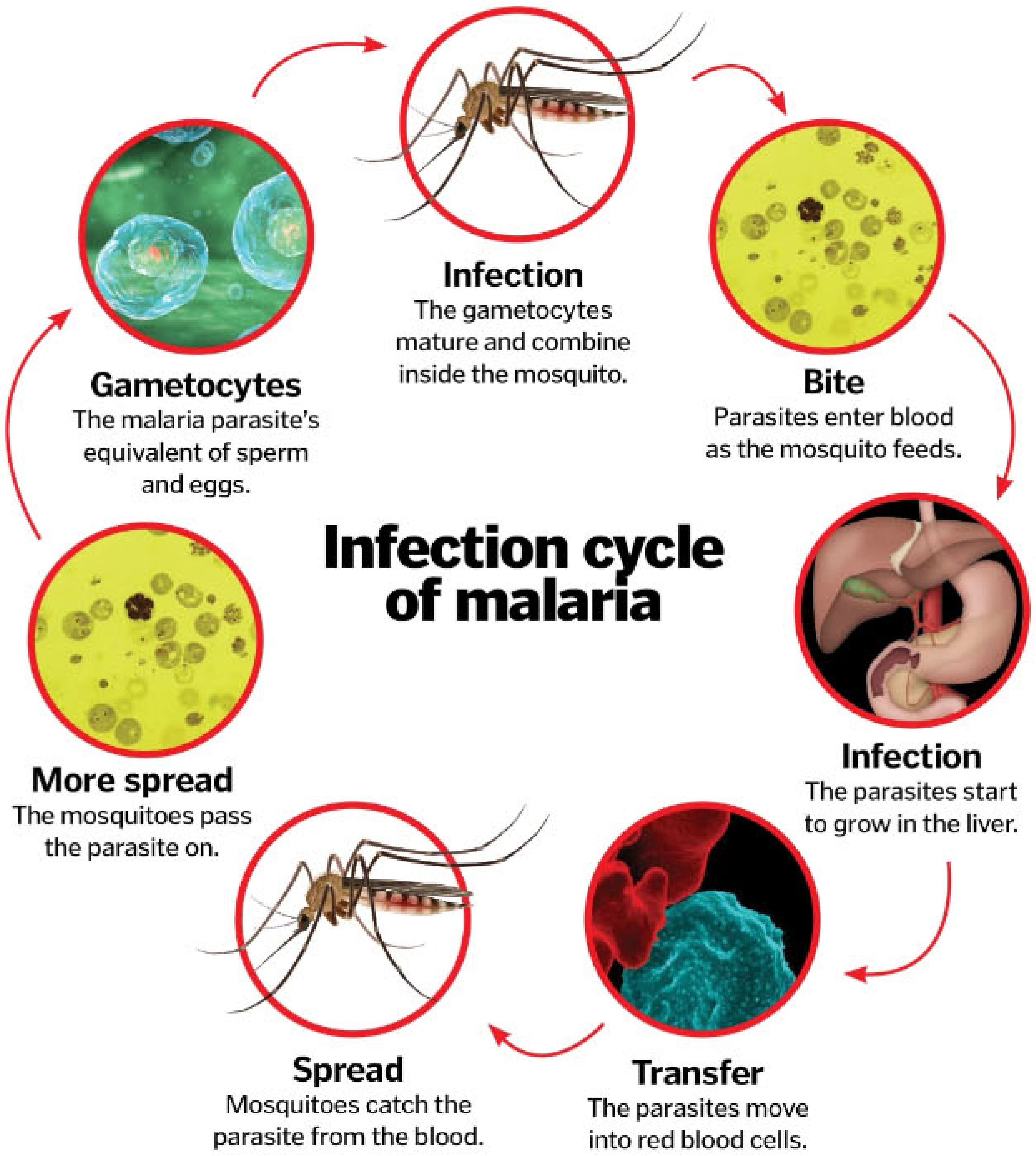
Global elimination is tough

The World Health Organisation first initiated an attempt to rid the world of malaria in 1955. The idea was to use a combined attack, spraying houses to get rid of the mosquitoes, and using antimalarials to kill the parasites. They had some successes in areas where the climate was moderate and mosquitoes thrive only during certain seasons, but in other places the program didn't work as well.

Mosquitoes started to become resistant to pesticides, and the parasites resistant to treatments. This, combined with wars, political unrest, and patchy access to resources, meant that coordinating a global attack against malaria became almost impossible.

In 2015, the WHO reissued their challenge. But today we are facing even stronger versions of the parasite and vector, and new weapons are needed to eliminate them.

Infection cycle of malaria



Infection
The gametocytes mature and combine inside the mosquito.

Bite
Parasites enter blood as the mosquito feeds.

Infection
The parasites start to grow in the liver.

Transfer
The parasites move into red blood cells.

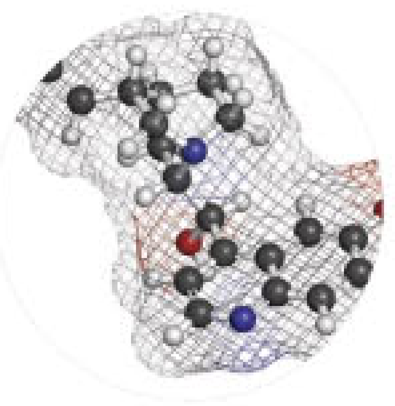
Spread
Mosquitoes catch the parasite from the blood.

More spread
The mosquitoes pass the parasite on.

Gametocytes
The malaria parasite's equivalent of sperm and eggs.

Timeline

1600s
Peruvian tree bark is used to treat malaria, eventually leading to the modern drug quinine.



1880
The parasite that causes malaria is discovered in blood samples taken from patients.

1897
It's discovered that mosquitoes are able to transmit malaria from one person to another.

1939
The DDT pesticide is invented, allowing people to control numbers of malaria-carrying mosquitoes.

1951
Malaria is wiped out in the US after a government eradication program sprays millions of homes.

2015
The World Health Organisation endorses a new strategy to eliminate malaria for good.

Future
Malaria-carrying mosquitoes are wiped out by genetically modified insect mates.

Future
The world is declared malaria free thanks to the eradication campaign.

10-18
days it takes for malaria parasites to reproduce inside a mosquito

Malaria was first written about in Ancient China in 2700 BCE

3.2
billion people live in regions where they could catch malaria

400,000
people die of malaria each year

70%
of malaria deaths are children under the age of five

Malaria is caused by parasites that infect humans and mosquitoes

Spraying houses with insecticide is the best way to stop transmission

Last year **95** countries reported cases of malaria

214 Million
cases of malaria in 2015

© Thinkstock

Halting heart attacks and strokes

Diseases of the heart and blood vessels are the world's biggest killers

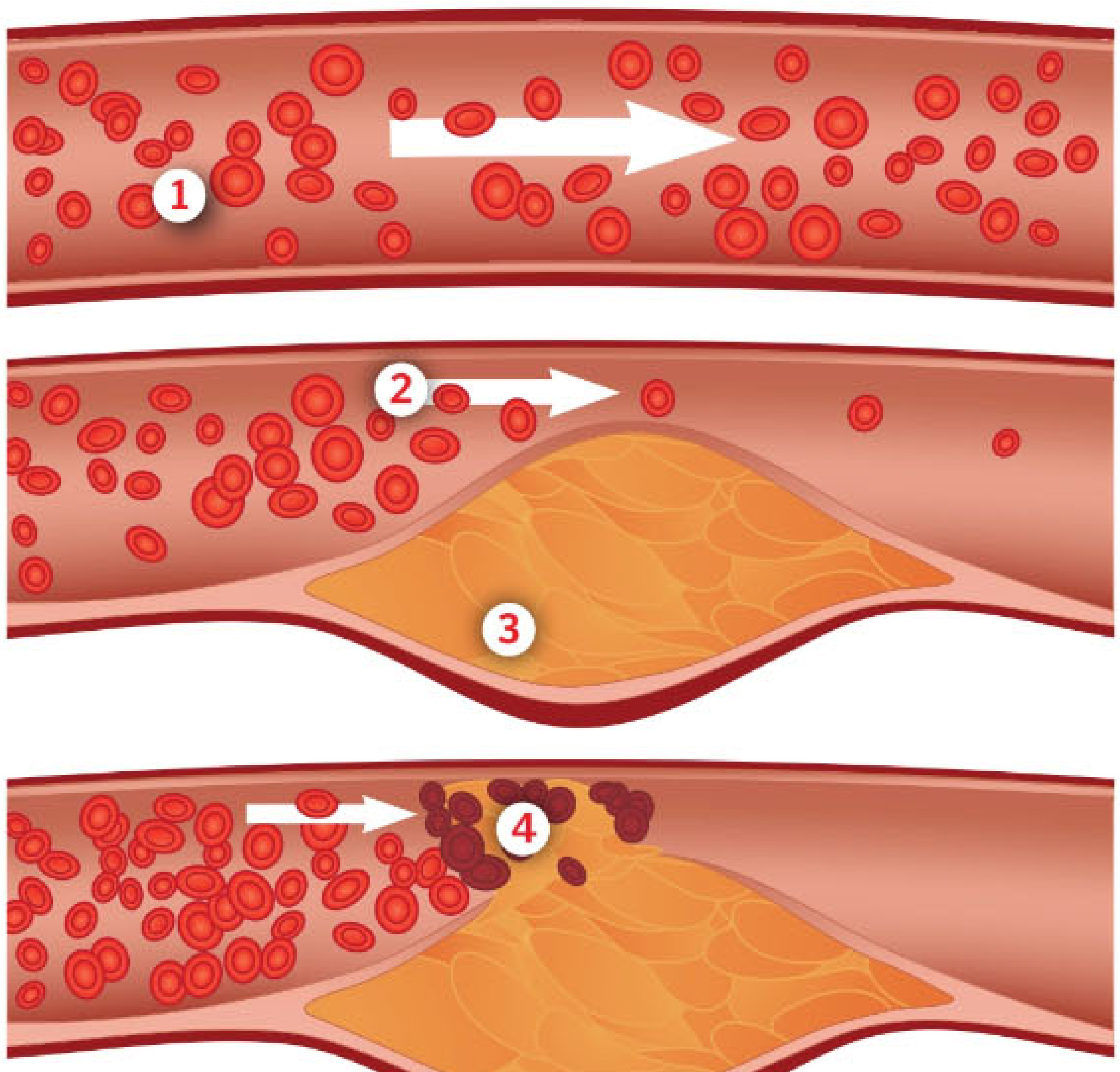
When arteries and veins become clogged with fat, rough plaques form and narrow the tubes. As the blood tries to force its way through it swirls and twists, and more damage is done. The fatal blow comes when parts of the blockage break away. Clotting molecules in the blood interpret the roughness as a cut that needs to be sealed. They start to build a clot, and as the circulating blob gets larger, it eventually becomes lodged in the tubes, cutting off the blood supply.

The damage can't always be repaired, but the latest research could change that for the future. Stem cells are cells that haven't yet decided which part of the body to become. With some coaxing in the lab, they can be converted into new blood cells, new skin cells, or even new heart muscle. Harvard scientists have already made a life-size beating heart by convincing stem cells to become heart muscle and growing them on a scaffold. In the future, custom organ replacements could be made artificially on demand.

If this doesn't work, another option is gene therapy, which is already being trialled for heart failure. Genes are delivered to the cells, telling them to make different molecules, and potentially allowing the body to be reprogrammed from the inside out.

How heart disease starts

The slow accumulation of fat can lead to a deadly blood clot



1 Normal vessel Healthy blood vessels have smooth internal walls, allowing the blood to slip easily around the body.

2 Disruption When a blockage appears in the vessel, the blood quickly becomes backed up.

3 Plaque Fatty deposits in the wall of the blood vessel cause it to bulge, narrowing the tube.

4 Clotting A clot starts to form on the roughened surface, and the blood vessel becomes clogged.

Why haven't we cured it?

Cardiovascular disease is difficult to treat once a catastrophic event has happened; strokes and heart attacks deprive vital organs of oxygen, and the affected tissue quickly dies. If you have a heart attack outside of a hospital, you have just a one in ten chance of surviving, and quarter of people who suffer a stroke will die within a year.

In order to meanigfully improve treatment of cardiovascular disease, we need to be able to repair or replace damaged tissues, or we need to prevent it happening in the first place. Neither one is easy to do.

Timeline

1899 Pharmaceutical company Bayer begin manufacturing a new drug called aspirin in Germany.

1930 The defibrillator is invented, allowing stopped hearts to be restarted with electricity.

1958 The first implantable pacemaker is installed, allowing the heart to be controlled.

1960 The first heart bypass surgery was performed to divert blood around damaged vessels.

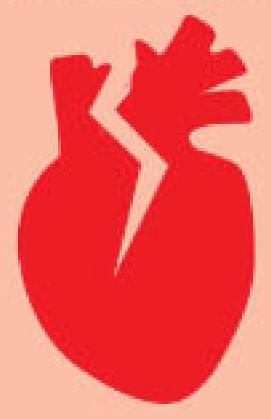
1967 The first human heart transplant is performed, allowing damaged organs to be replaced.

1987 The first cholesterol-lowering statin drug hits the market, helping to prevent heart attacks.

Future Custom-grown replacement hearts are produced from people's own stem cells.

Future Gene therapy is used to reverse the damage done by heart attacks.

Cardiovascular disease killed **17.2** million people in 2012



Heart attack symptoms include chest, arm and jaw pain, sweating and vomiting

Someone has a stroke every 2 seconds

There are over 2.5 million heart attack and stroke survivors in the UK

♂ Men are more likely to die of heart disease than women ♀

A third of adults in the UK have high cholesterol

The most important risk factors are smoking, diet, exercise and alcohol intake

Stroke symptoms include sudden weakness on one side of the body, confusion and slurred speech

Heart disease and stroke are the first and second most common causes of death

SAVING LIVES WITH NANOTECH

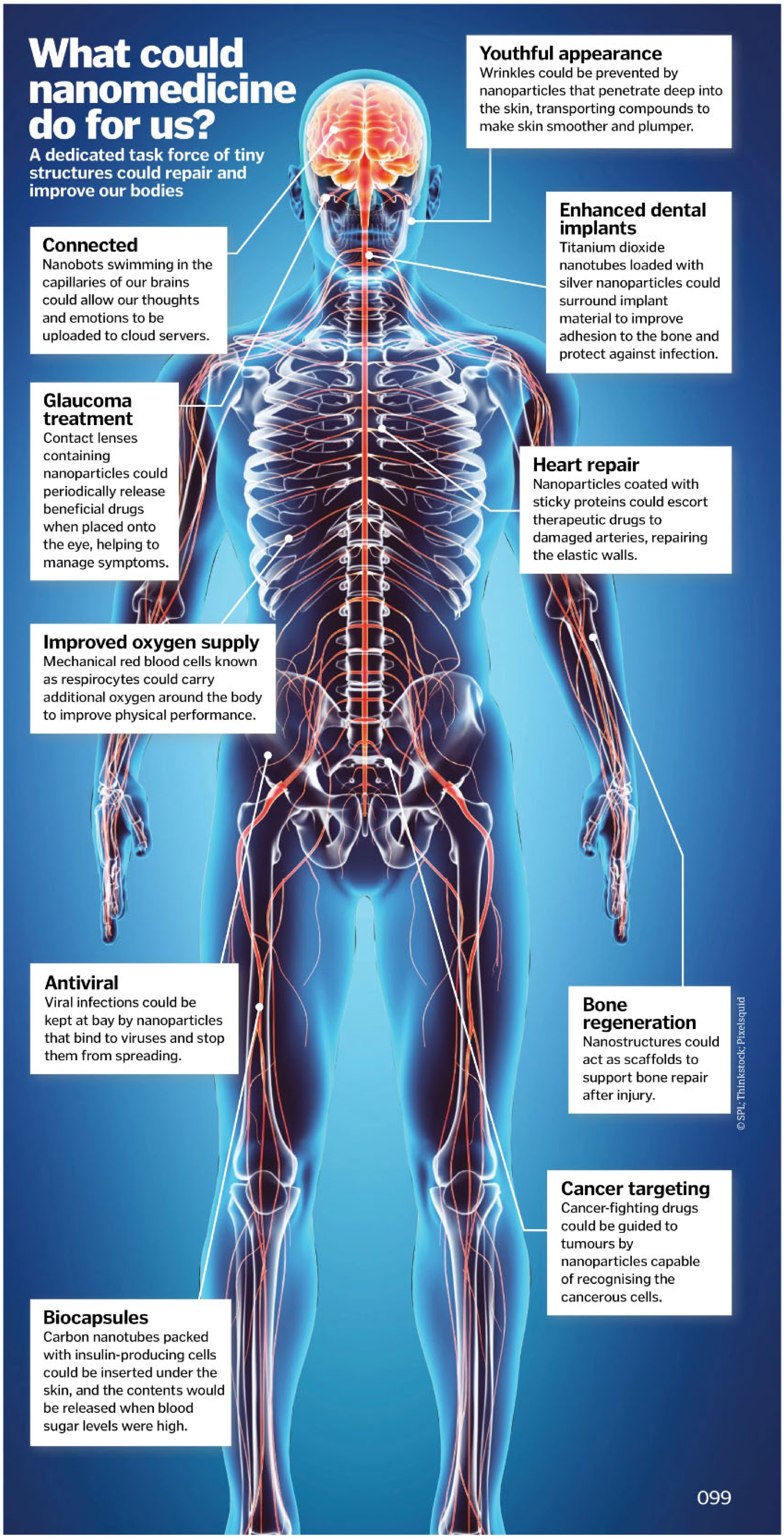
DID YOU KNOW? *Some nanomaterials are naturally occurring, including volcanic ash, smoke particles and sea spray*

Meet the minuscule medics that could conquer incurable disease

What if we could control entire systems on the molecular level? What if inside your cells you had millions of helpers; tiny guardians tasked with clearing toxins from your body and keeping you in tip-top condition, removing pathogens before they have a chance to cause harm? This is one of the main goals of nanotechnology – an advanced field championed by scientists, engineers and mathematicians who are busy developing machines that would fit inside the eye of a needle.

It may seem truly exceptional and perhaps impossible, but all living organisms rely on machines such as these. Some species of bacteria, for example, propel themselves along using a spinning tail called a flagellum, which is powered by a rotating motor built from a ring of proteins. This operates in much the same way as the mechanical variants we use in industry, but just on a much smaller scale. Our own cells are also filled with dedicated machinery known as organelles that are responsible for certain jobs including the assembly, packaging and transport of materials inside and outside of the cell. The ribosome is one such example of a complex machine that fits nicely inside a cell, where it efficiently assembles proteins from genetic code. So our bodies are already packed with natural nanotech, but now the goal is to manufacture the artificial kind.

Synthetic structures are identified as pieces of nanotechnology when they range in size from one to 100 nanometres, so even at their largest they're 5,000 times smaller than this full stop. They're incredibly small pieces of tech! Nanotechnology has a wide range of potential applications, particularly in medicine, where nanomachines



What could nanomedicine do for us?

A dedicated task force of tiny structures could repair and improve our bodies

Connected
Nanobots swimming in the capillaries of our brains could allow our thoughts and emotions to be uploaded to cloud servers.

Glaucoma treatment
Contact lenses containing nanoparticles could periodically release beneficial drugs when placed onto the eye, helping to manage symptoms.

Improved oxygen supply
Mechanical red blood cells known as respirocytes could carry additional oxygen around the body to improve physical performance.

Antiviral
Viral infections could be kept at bay by nanoparticles that bind to viruses and stop them from spreading.

Biocapsules
Carbon nanotubes packed with insulin-producing cells could be inserted under the skin, and the contents would be released when blood sugar levels were high.

Youthful appearance
Wrinkles could be prevented by nanoparticles that penetrate deep into the skin, transporting compounds to make skin smoother and plumper.

Enhanced dental implants
Titanium dioxide nanotubes loaded with silver nanoparticles could surround implant material to improve adhesion to the bone and protect against infection.

Heart repair
Nanoparticles coated with sticky proteins could escort therapeutic drugs to damaged arteries, repairing the elastic walls.

Bone regeneration
Nanostructures could act as scaffolds to support bone repair after injury.

Cancer targeting
Cancer-fighting drugs could be guided to tumours by nanoparticles capable of recognising the cancerous cells.

© SPL; Thinkstock; Pixelsquid

could move freely through our vessels to support and repair our cells and tissues. While the idea of these mini-medics is theoretical for now, drugs involving nanoparticles are currently being used to treat certain diseases.

Nanomedicine could also join the fight against cancer. Already in labs across the world, scientists have started to develop pieces of nanotech capable of identifying cancer in its early stages, just by testing a small amount of blood or saliva. Once perfected, this could be a huge milestone in diagnosing a disease that is currently very difficult to notice before tumours have grown. Even if these reporters are not used in time then nanoparticles could come to save the day, having also been used as homing missiles to deliver chemotherapy drugs directly to cancer cells.

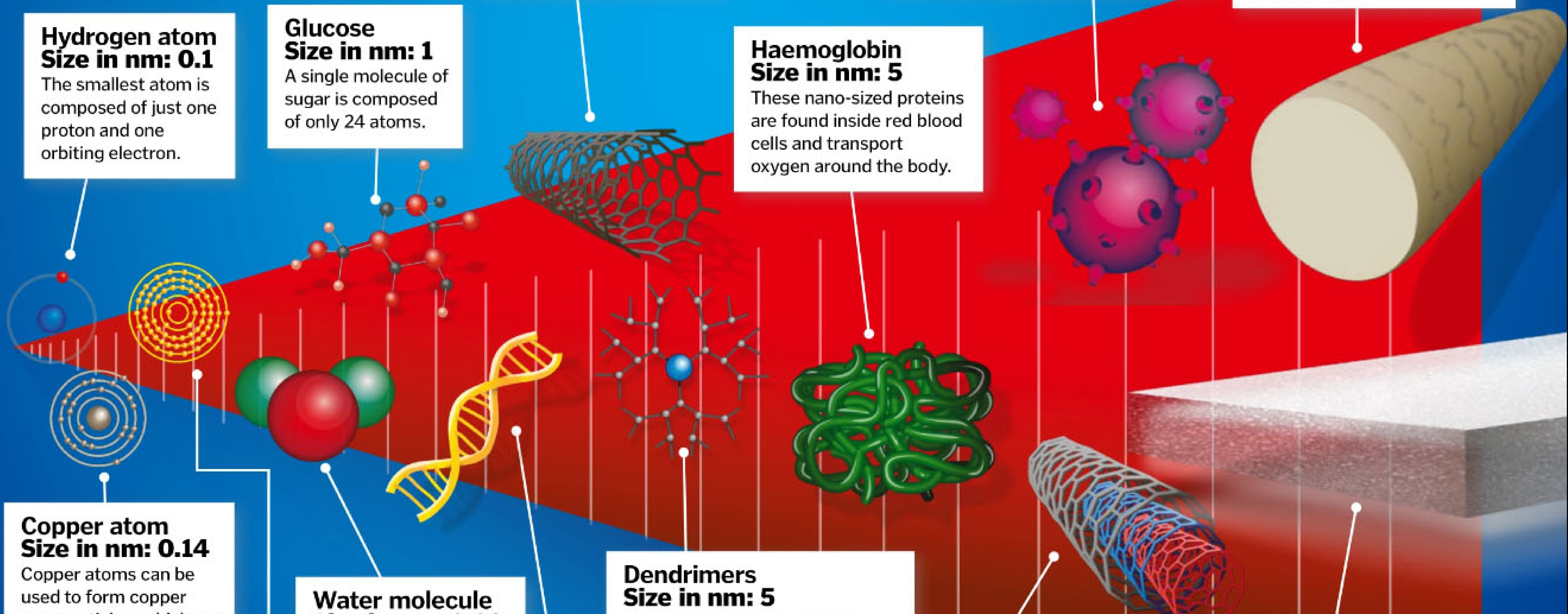
New methods of fighting disease are an exciting prospect, but nanotechnology promises even more. Currently incurable disorders like degenerated and severed neurons that lead to paralysis could be healed with nanostructures in the future, and researchers plan to use nanomachines to patrol the cells and systems of our bodies to prevent diseases before they have the chance to cause damage. These envisioned nanobots could be remote-controlled externally or left to roam the body freely. We will even be able to equip them with minuscule arms for clearing unwanted molecules and power them with motors much like the ones found in bacteria.

And we needn't stop at keeping ourselves healthy, as nanotechnology could also be used to enhance our bodies beyond their natural capabilities. Our stamina and endurance could be massively improved by using nanoparticles to carry extra molecules of oxygen in the bloodstream to support the work of red blood cells. This could grant us the ability to hold our breath for several hours underwater – in theory, nanotechnology could be the tool that creates the very first superhumans.

Right now, nanotechnology is still in its early stages, but it is already being incorporated into everyday items, including sun creams, clothing and waterproof phone coatings. Building things hundreds of times smaller than the text you're reading is very tricky, and particles don't always play by the same rules as we do. At the atomic level, the laws of physics as we experience them no longer wholly apply, and we enter the realm of quantum mechanics. Despite these obstacles, advances in technology allow us to peer into this invisible world, and to see and interact with structures at an atomic scale. As we learn more about the properties of certain atoms and molecules, we will be able to manipulate matter at the nanoscale to develop new and improved materials and structures. From engineering to medicine, the building blocks of tomorrow's tech are set to be very small indeed.

How small is small?

The nanoscale takes the definition of tiny to a whole new level



Hydrogen atom
Size in nm: 0.1
The smallest atom is composed of just one proton and one orbiting electron.

Glucose
Size in nm: 1
A single molecule of sugar is composed of only 24 atoms.

Single-walled carbon nanotubes
Size in nm: 1
Sheets of graphene rolled into cylinders create tiny tubes close to 1nm wide.

Haemoglobin
Size in nm: 5
These nano-sized proteins are found inside red blood cells and transport oxygen around the body.

White blood cells
Size in nm: 5,000-20,000
Your body contains several different types of white blood cell, all of which are small enough to migrate out of blood vessels.

Human hair
Size in nm: 80,000
A 'hair's breadth' is used to describe an incredibly small distance, but most hairs are at least 800 times wider than nanomachines.

Copper atom
Size in nm: 0.14
Copper atoms can be used to form copper nanoparticles, which are used for a variety of purposes in medicine and electronics.

Water molecule
Size in nm: 0.28
Two atoms of hydrogen and one atom of oxygen come together to form this small molecule.

Dendrimers
Size in nm: 5
These synthetic molecules are made of a central core surrounded by branch-like structures and coated with an outer shell. They can be used for drug delivery.

Gold atom
Size in nm: 0.14
Atoms of gold can be assembled to form nanoparticles known as colloidal gold.

DNA helix
Size in nm: 2
Your DNA is cleverly coiled and packed to fit inside the cell nucleus. If stretched straight and joined together, each nucleus' DNA would be two metres long!

Multi-walled carbon nanotubes
Size in nm: 2-50
These synthetic nanostructures are built using rings of carbon atoms that are arranged in multiple layers of tubes.

Sheet of paper
Size in nm: 90,000
Although it may appear incredibly thin to us, over 450,000 atoms form the width of a sheet of paper.

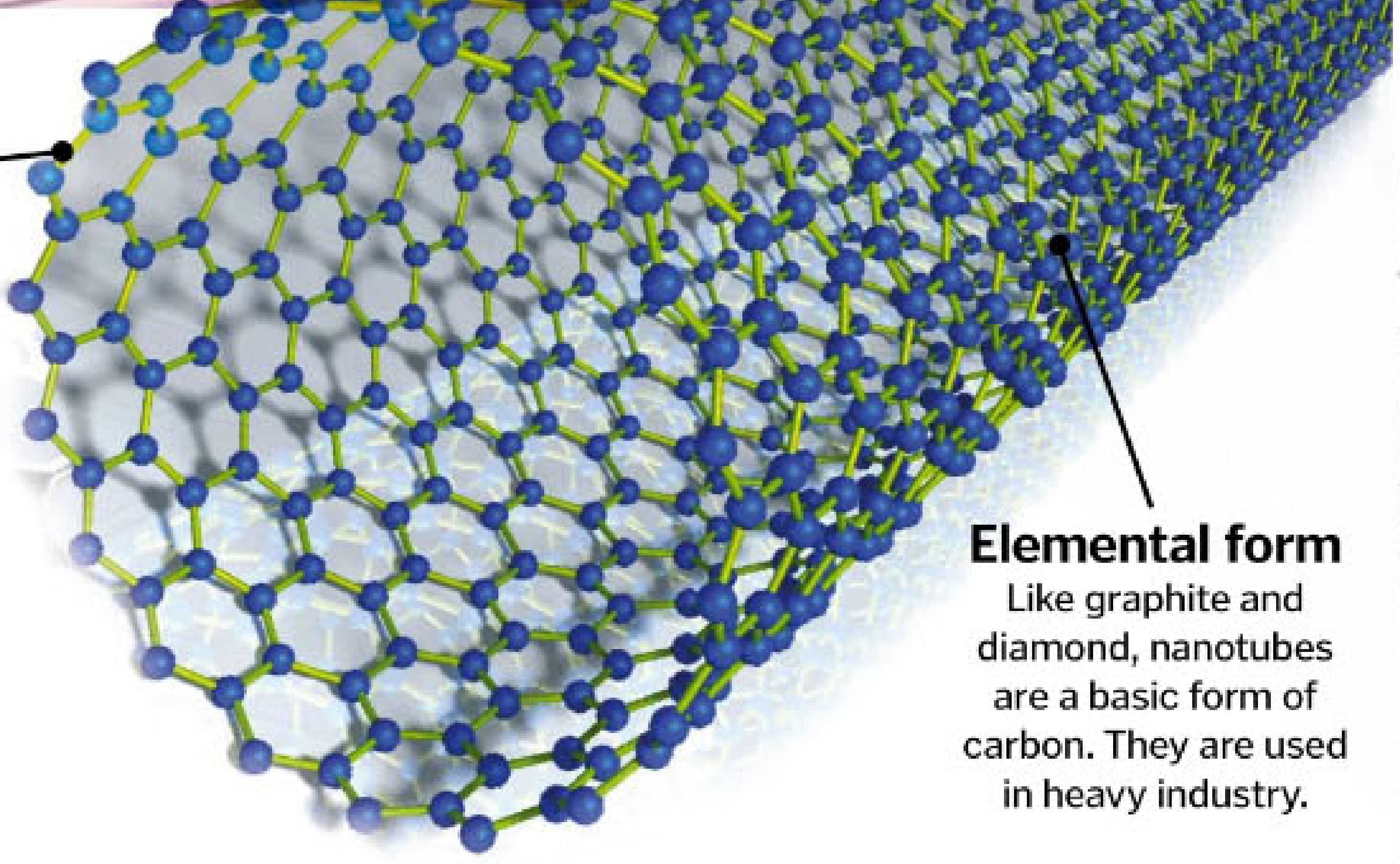
DID YOU KNOW? *Silkworms produce stronger silk if they're fed carbon nanotubes*

TYPES OF NANOTECHNOLOGY

What objects can we create by manipulating molecules and atoms?

Much like natural nano-sized structures and molecules, synthetic pieces of nanotechnology are a diverse group. By using our knowledge of how atoms are arranged into structures, we can design and model different shapes with a wide range of properties. Nanotechnology can vary from relatively simple to immensely complex structures: some are used solely as protective housings with the responsibility of transporting drugs, and others have intricate mechanical actions such as mimicking a wheel spinning on an axle.

Microscopic motors
While not strictly nanotechnology, microscopic motors can serve as a stepping stone in order to develop even smaller structures. Once we can build small enough motors, they could theoretically power medical nanobots.

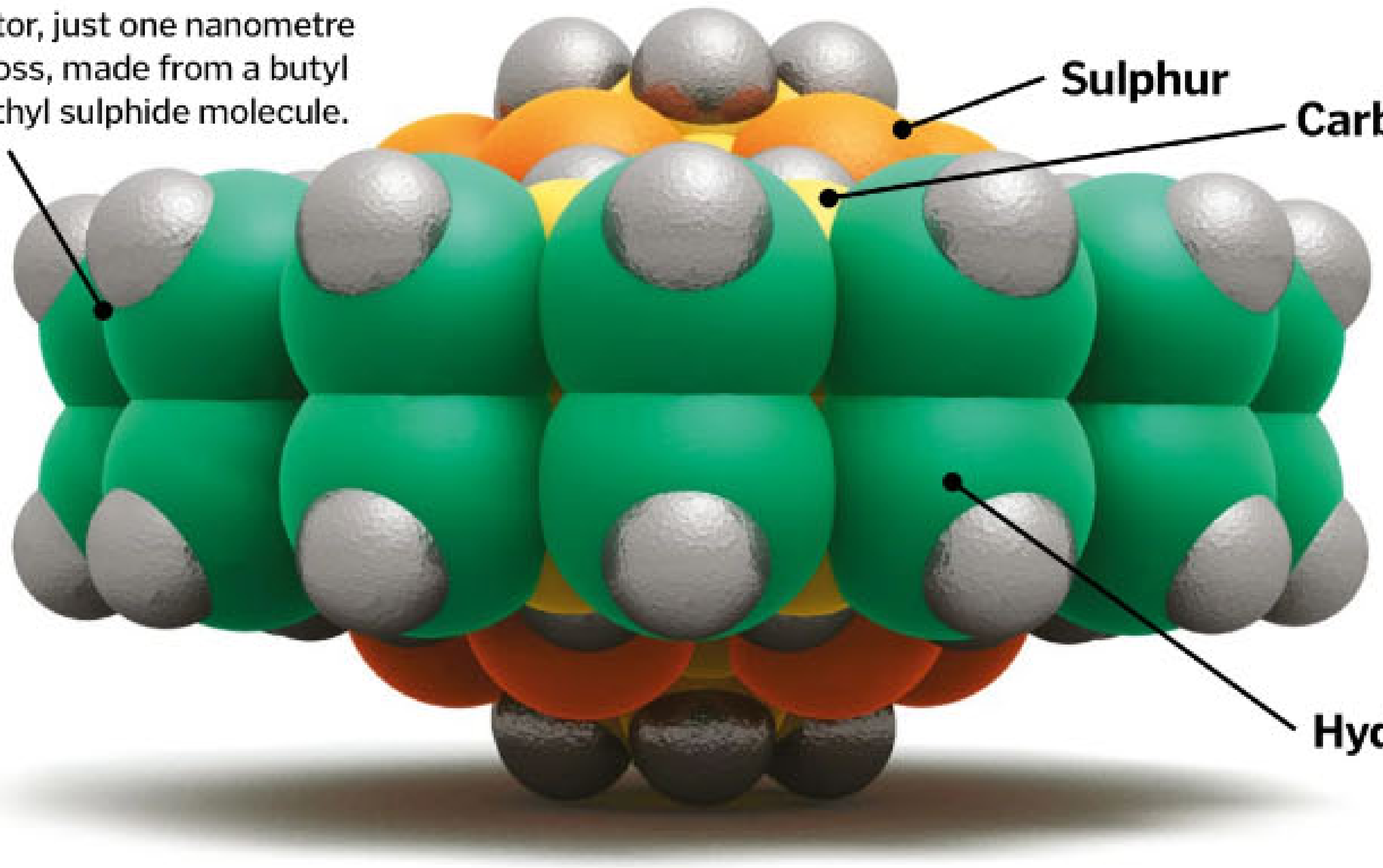


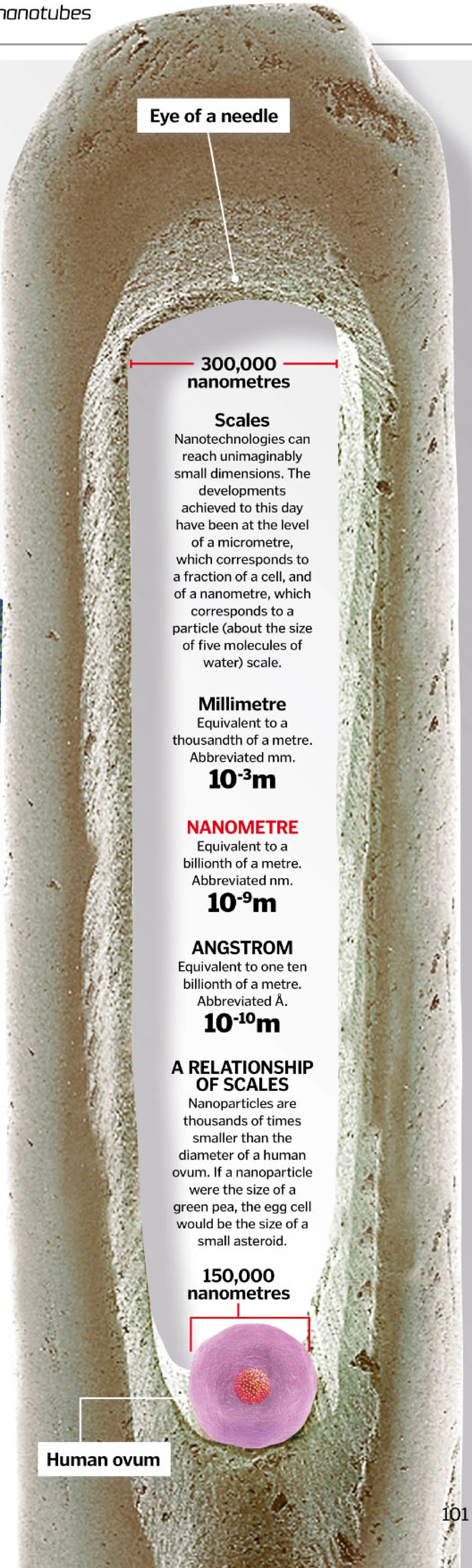
Nanotubes
These cylindrical structures can be just a nanometre wide, but reach lengths of 20 centimetres – that means they are 200 million times longer than they are wide! They are built using carbon that's arranged in rings.

Elemental form
Like graphite and diamond, nanotubes are a basic form of carbon. They are used in heavy industry.

Engineered nanomolecules
Molecules can be modified and manipulated to build custom nanomachines. In 2011, a team of researchers created the smallest-ever electric motor, just one nanometre across, made from a butyl methyl sulphide molecule.

> *"Nanotechnology can vary from relatively simple to immensely complex structures"*





Scales
Nanotechnologies can reach unimaginably small dimensions. The developments achieved to this day have been at the level of a micrometre, which corresponds to a fraction of a cell, and of a nanometre, which corresponds to a particle (about the size of five molecules of water) scale.

Millimetre
Equivalent to a thousandth of a metre. Abbreviated mm.
10^{-3}m

NANOMETRE
Equivalent to a billionth of a metre. Abbreviated nm.
10^{-9}m

ANGSTROM
Equivalent to one ten billionth of a metre. Abbreviated Å.
10^{-10}m

A RELATIONSHIP OF SCALES
Nanoparticles are thousands of times smaller than the diameter of a human ovum. If a nanoparticle were the size of a green pea, the egg cell would be the size of a small asteroid.

© Solgo; Pixelsquid; Shutterstock; Illustration by The Art Agency

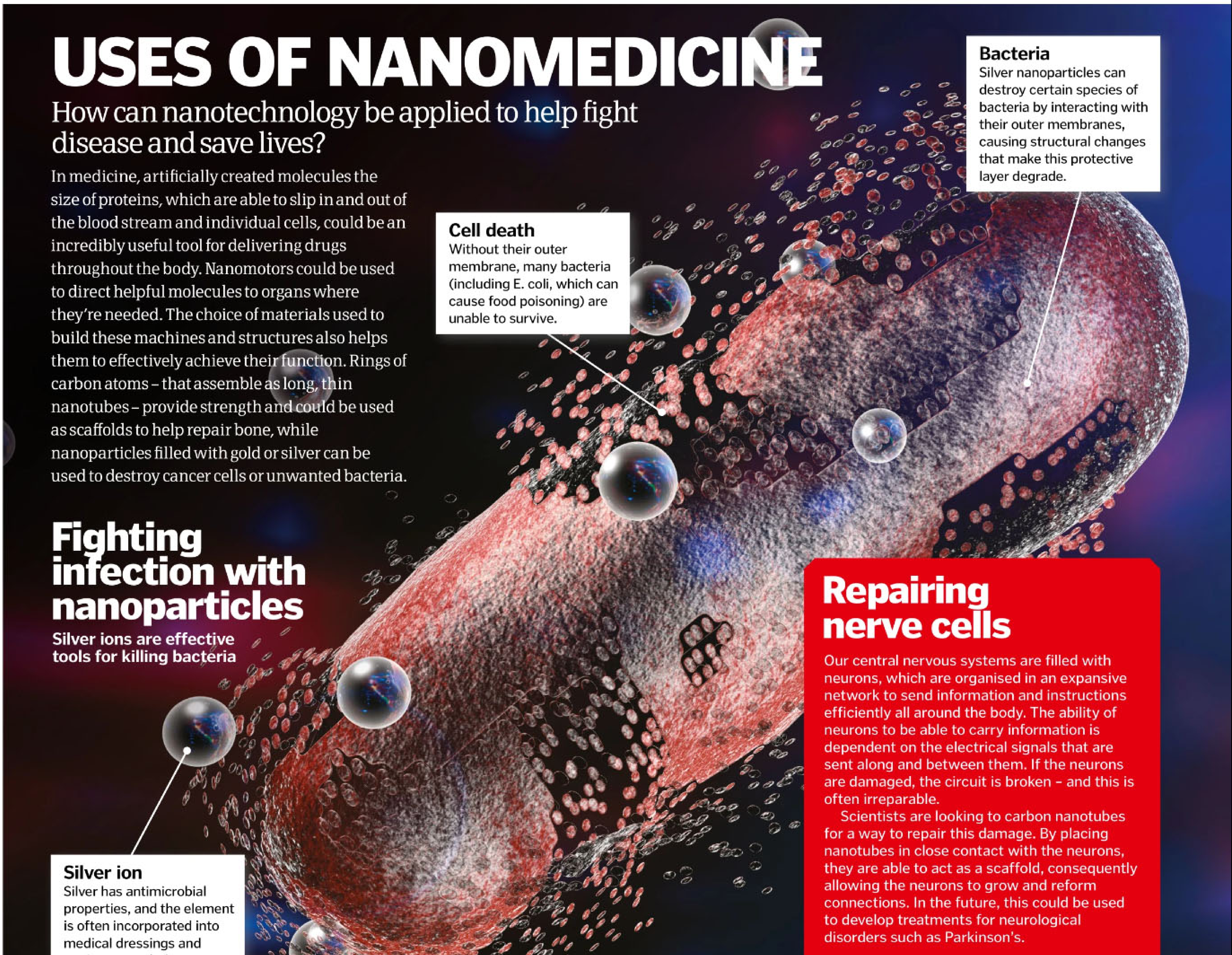
USES OF NANOMEDICINE

How can nanotechnology be applied to help fight disease and save lives?

In medicine, artificially created molecules the size of proteins, which are able to slip in and out of the blood stream and individual cells, could be an incredibly useful tool for delivering drugs throughout the body. Nanomotors could be used to direct helpful molecules to organs where they're needed. The choice of materials used to build these machines and structures also helps them to effectively achieve their function. Rings of carbon atoms – that assemble as long, thin nanotubes – provide strength and could be used as scaffolds to help repair bone, while nanoparticles filled with gold or silver can be used to destroy cancer cells or unwanted bacteria.

Fighting infection with nanoparticles

Silver ions are effective tools for killing bacteria



Bacteria
Silver nanoparticles can destroy certain species of bacteria by interacting with their outer membranes, causing structural changes that make this protective layer degrade.

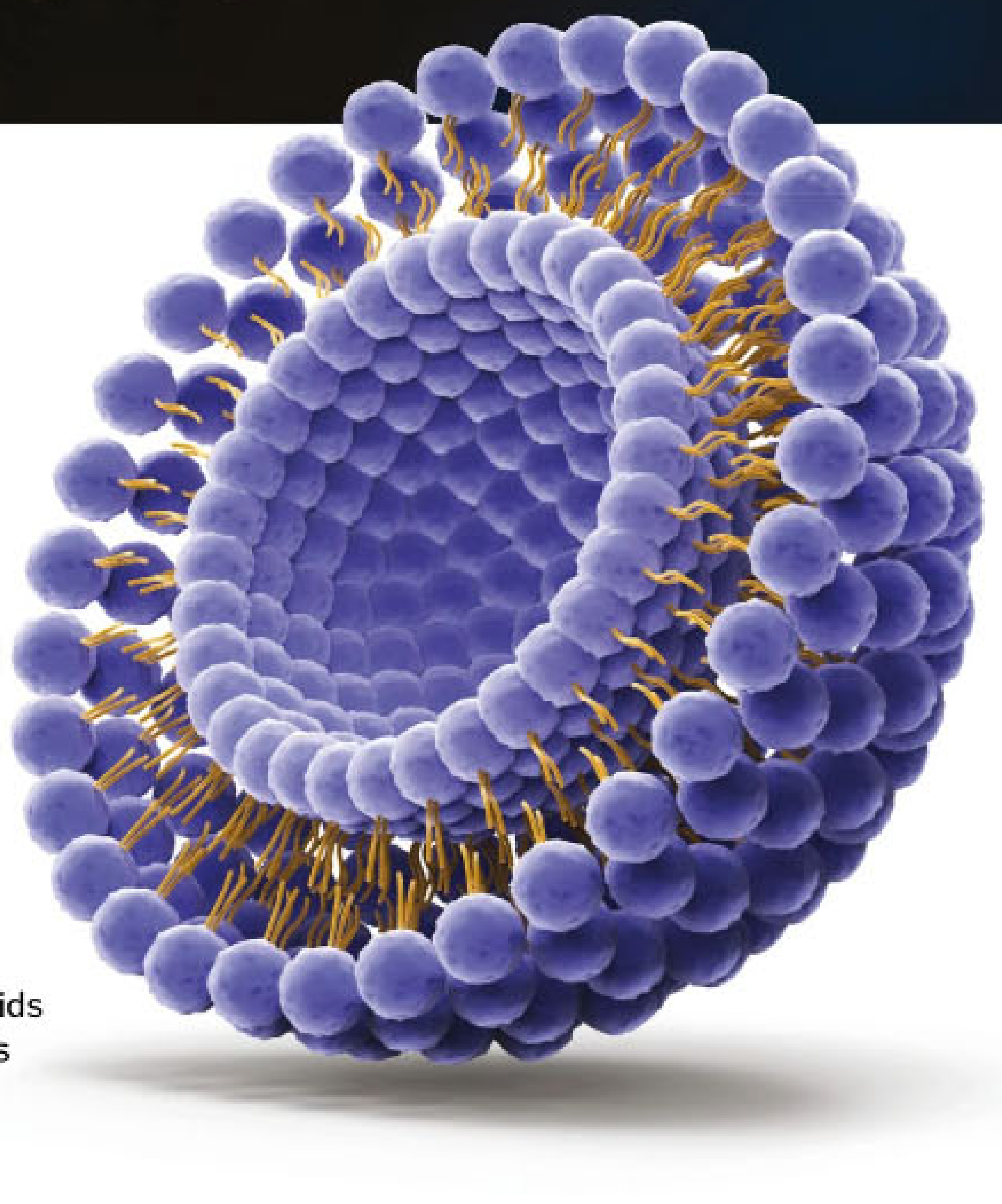
Cell death
Without their outer membrane, many bacteria (including E. coli, which can cause food poisoning) are unable to survive.

Silver ion
Silver has antimicrobial properties, and the element is often incorporated into medical dressings and equipment to help prevent and fight infections.

Drug delivery

Ensuring that therapeutic drugs reach their cell targets is no easy task when you're dealing with a complex organism like a human. Drugs may not arrive at the right destination, and those that do may not be able to enter the cells. The use of nanoparticles called liposomes – which are able to carry drugs into cells – may be a way to overcome this obstacle.

Liposomes surround the drug particles and help guide them to their destination. Once a liposome makes contact with a cell, it is slowly engulfed in a process called endocytosis. The liposome usually breaks down slowly inside the cell, but X-rays can be used to rupture the fatty layers more rapidly, so that they release their tiny parcels of drugs.

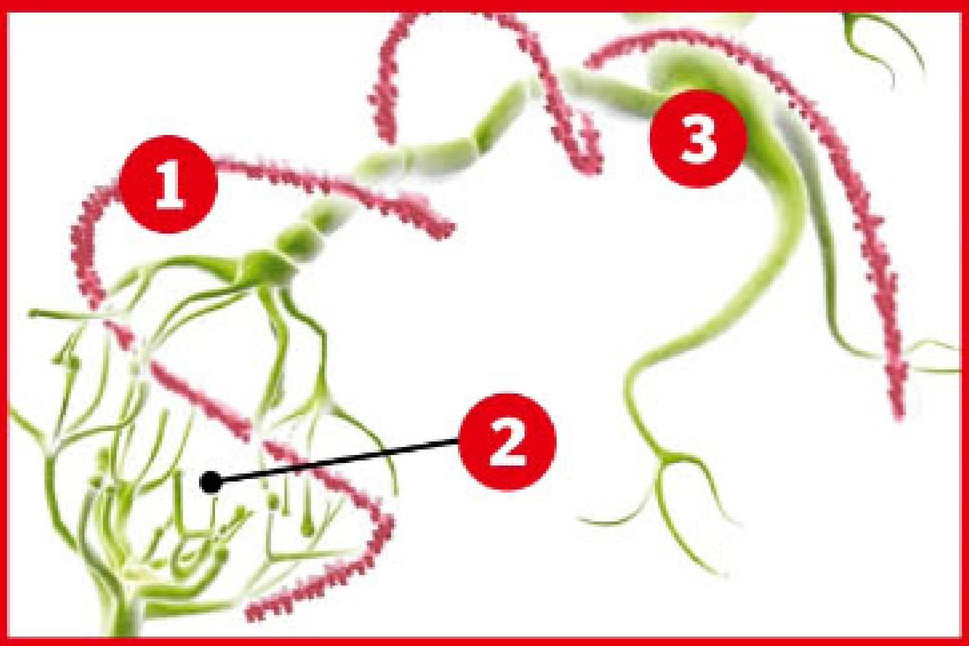


Liposomes are nanoscale 'bubbles' made of phospholipids – the same molecules that make up our cell membranes

Repairing nerve cells

Our central nervous systems are filled with neurons, which are organised in an expansive network to send information and instructions efficiently all around the body. The ability of neurons to be able to carry information is dependent on the electrical signals that are sent along and between them. If the neurons are damaged, the circuit is broken – and this is often irreparable.

Scientists are looking to carbon nanotubes for a way to repair this damage. By placing nanotubes in close contact with the neurons, they are able to act as a scaffold, consequently allowing the neurons to grow and reform connections. In the future, this could be used to develop treatments for neurological disorders such as Parkinson's.



1 Nanotube mesh
Nanotubes occupy space around the neurons. This provides a scaffold for the neurons and helps to guide their growth.

2 Neuron connection
Neurons have to be close to one another to communicate. They can send chemical signals to each other across small gaps called synapses.

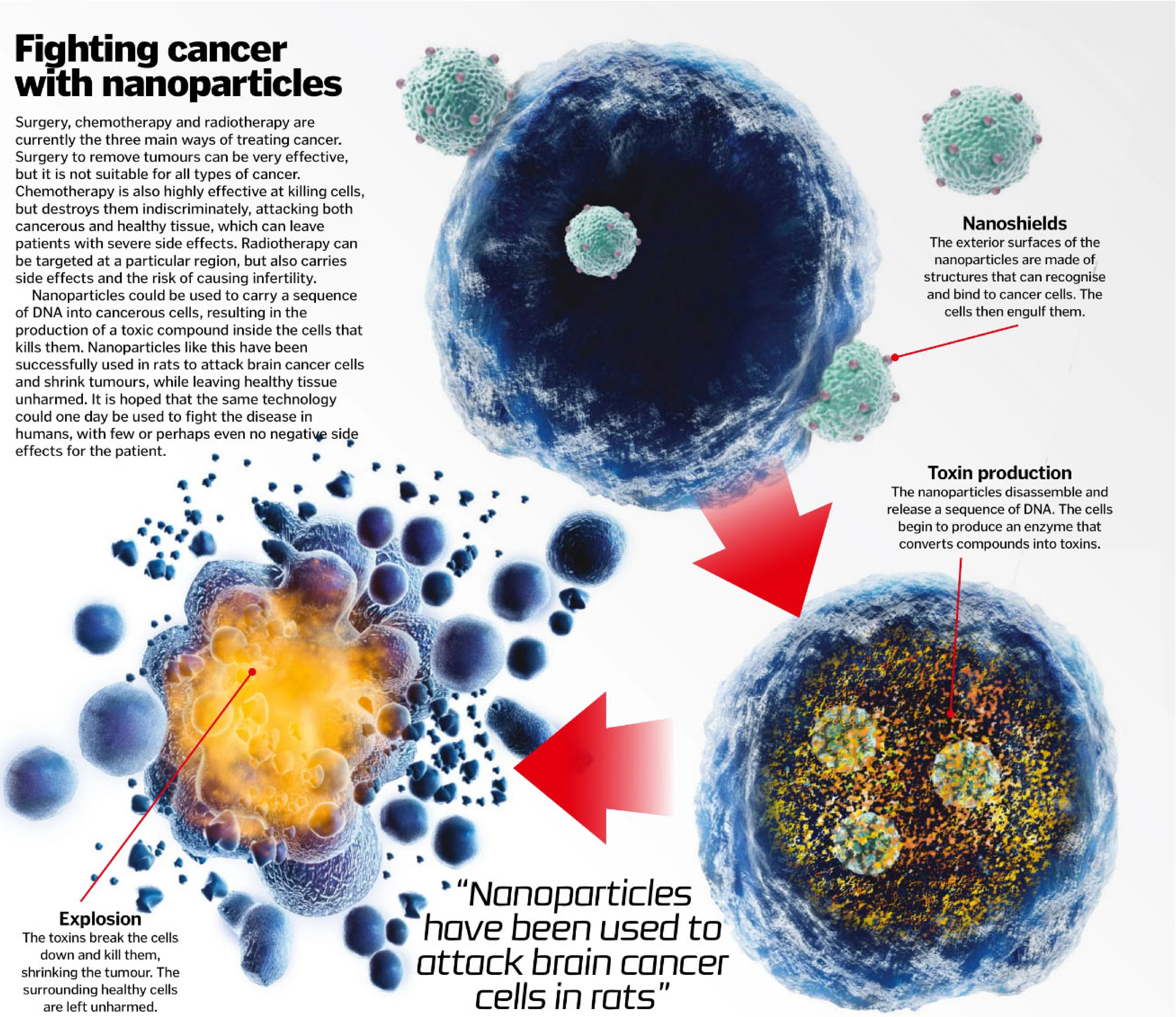
3 Regrowth
In the presence of the nanotubes, neurons can grow and re-establish contact with their neighbours.

DID YOU KNOW? *Nanoparticles of silver and gold were used by the Ancient Romans to decorate vases and chalices*

Fighting cancer with nanoparticles

Surgery, chemotherapy and radiotherapy are currently the three main ways of treating cancer. Surgery to remove tumours can be very effective, but it is not suitable for all types of cancer. Chemotherapy is also highly effective at killing cells, but destroys them indiscriminately, attacking both cancerous and healthy tissue, which can leave patients with severe side effects. Radiotherapy can be targeted at a particular region, but also carries side effects and the risk of causing infertility.

Nanoparticles could be used to carry a sequence of DNA into cancerous cells, resulting in the production of a toxic compound inside the cells that kills them. Nanoparticles like this have been successfully used in rats to attack brain cancer cells and shrink tumours, while leaving healthy tissue unharmed. It is hoped that the same technology could one day be used to fight the disease in humans, with few or perhaps even no negative side effects for the patient.



Nanoshields
The exterior surfaces of the nanoparticles are made of structures that can recognise and bind to cancer cells. The cells then engulf them.

Toxin production
The nanoparticles disassemble and release a sequence of DNA. The cells begin to produce an enzyme that converts compounds into toxins.

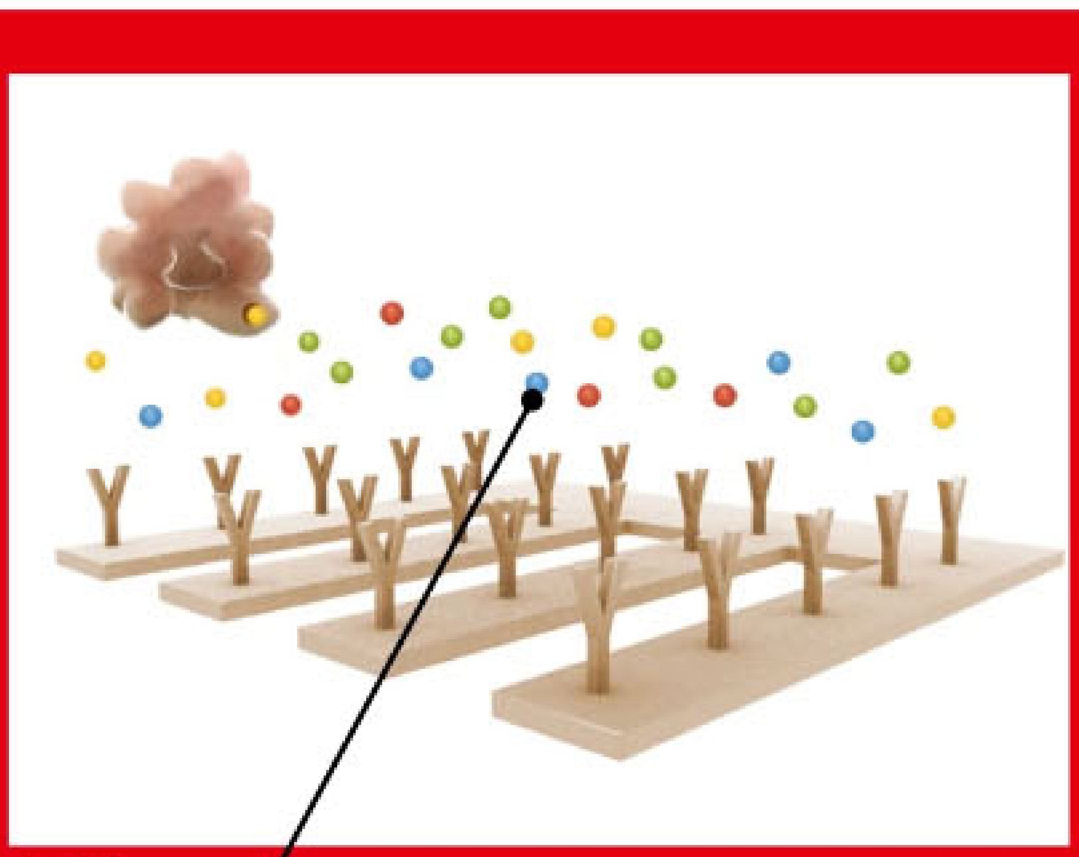
Explosion
The toxins break the cells down and kill them, shrinking the tumour. The surrounding healthy cells are left unharmed.

> "Nanoparticles have been used to attack brain cancer cells in rats"

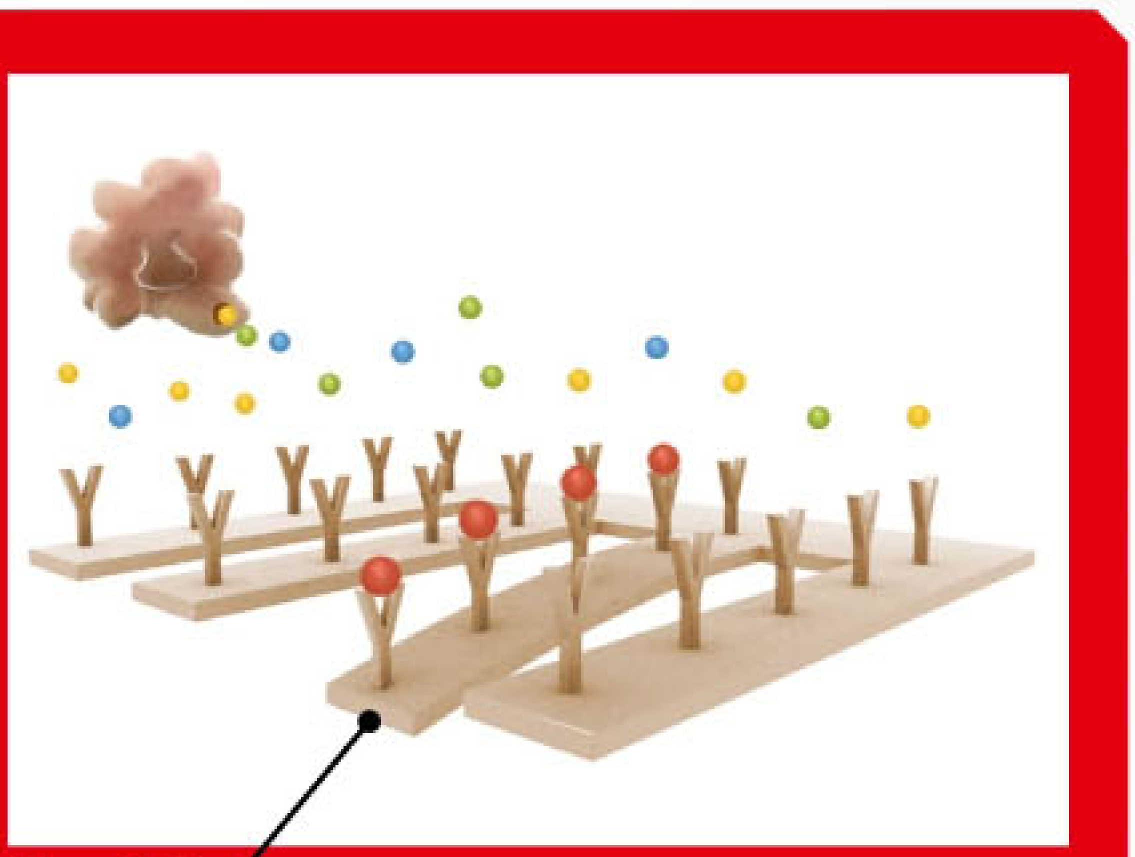
Detecting disease with nanocantilevers

Assembling structures on the molecular level can be very challenging, but one advantage is that small changes can have a large and detectable impact. In other words, adding single atoms or molecules can heavily influence their physical structure.

This idea has been used by scientists to create nanocantilevers. These nano-sized beams are covered in antibodies – small, Y-shaped proteins that recognise specific molecules. Cancer cells secrete molecules that bind to corresponding antibodies, forcing the beams to change shape. This concept could be used to quickly identify cancer in medical tests.



Evidence
Cancerous cells act very differently from healthy cells and produce certain proteins in much larger amounts. This leads to an abundance of certain molecules being released from the cell.



Verdict
The nanocantilever is coated with antibodies that attach to the molecules secreted by cancerous cells. The bound molecules then distort the shape of the nano-sized beams, which informs doctors that cancer is present.

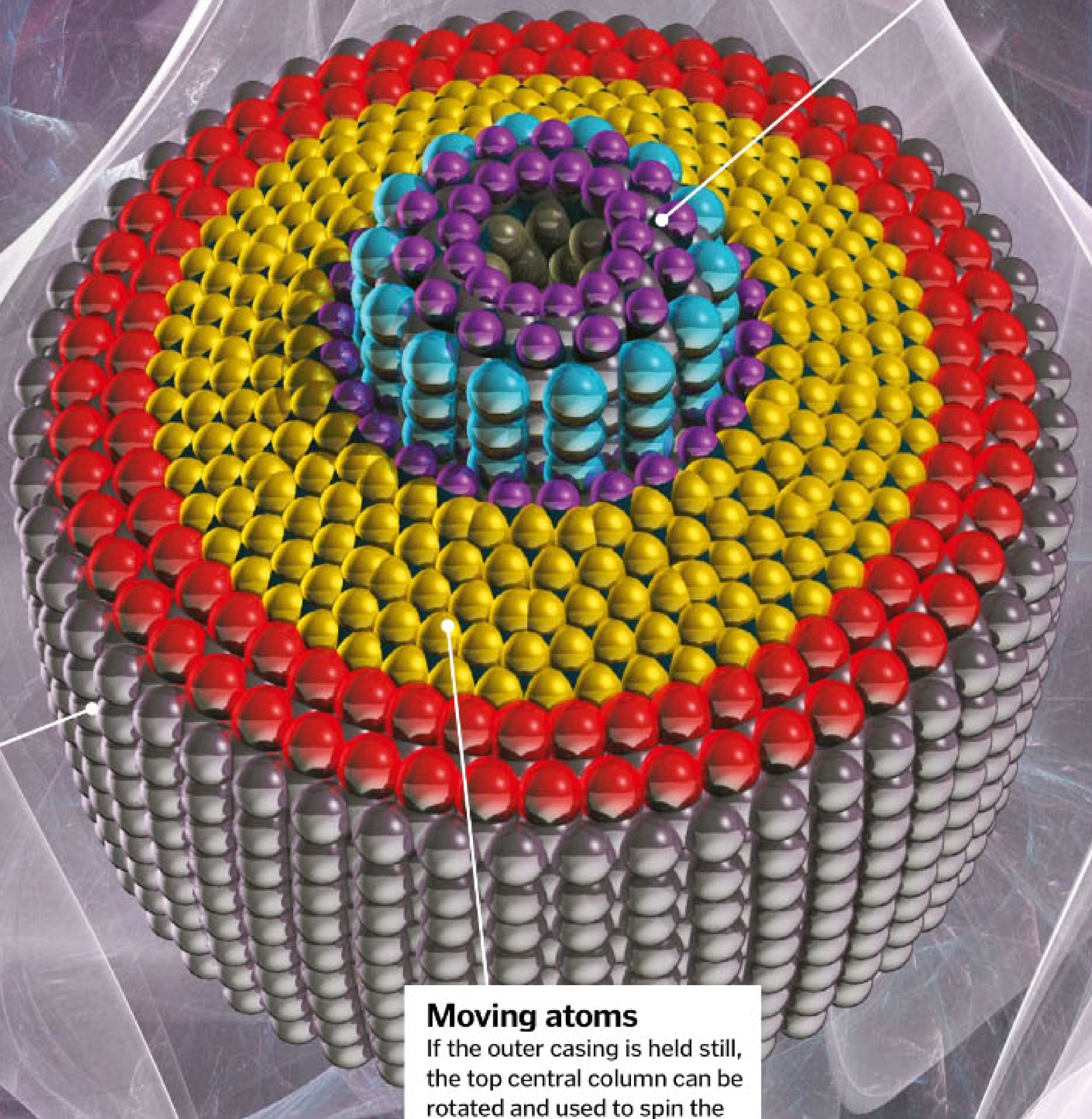
© SPL; Solgo

HOW TO BUILD A NANOBOT

Two methods are used to make things at the nanoscale: top-down or bottom-up

Assembling mini machines is no simple task, especially when we're talking about gears that only contain a few thousand atoms! Currently there are two quite different proposed methods of nanoconstruction: top-down and bottom-up. The top-down approach involves starting with a bulk of atoms and shaving away the parts you don't want, much like how a sculptor would carve away at a stone block until it assumed the form they wanted. Starting with a large amount of material makes this the more straightforward option, but every chunk that is cut away represents a considerable amount of waste, and the tools used for the task are so much larger than the final product that they are difficult to use accurately.

The alternative is the bottom-up approach, which is mostly still in the theoretical stage. This method involves building the nanobot atom by atom, or combining atoms in a way that lets them interact and self-assemble into the shape we want, which is of course quite complex! But when you're constructing controllable mechanical actions on the nanoscale, precision is everything, so the bottom-up approach will most likely take over in the future.



Bottom-up construction
Complex structures, such as this molecular gear, would only be able to achieve specific rotations if all the atomic parts were arranged very precisely, so bottom-up assembly would be required.

Assembly
A central column of atoms acts as an axle and is surrounded by other atoms that spin much like a wheel. The outer casing is formed of larger elements to reduce the number of atoms needed.

Moving atoms
If the outer casing is held still, the top central column can be rotated and used to spin the atoms between the shaft and external elements.

Everyday nanotech

It may seem futuristic, but nanotechnology is already here

Sunscreen

Zinc oxide and titanium dioxide are common ingredients in popular sun-protection products. Many modern lotions now use zinc oxide nanoparticles that are less visible on the skin than their larger counterparts.

Self-cleaning glass

A film of titanium dioxide just a few nanometres thick can be applied to sheets of glass, allowing the material to clean itself. The coating breaks down and loosens dirt, which is then washed away by rainwater.

Clothing

Antibacterial silver nanoparticles can be incorporated into certain fabrics that are used to make socks and sports clothing. These nanoparticles help to kill the bacteria that are responsible for sweaty smells.

DID YOU KNOW? *The 2016 Nobel prize in chemistry was awarded for the development of nanomachines*

How nanobots can be used to fight disease

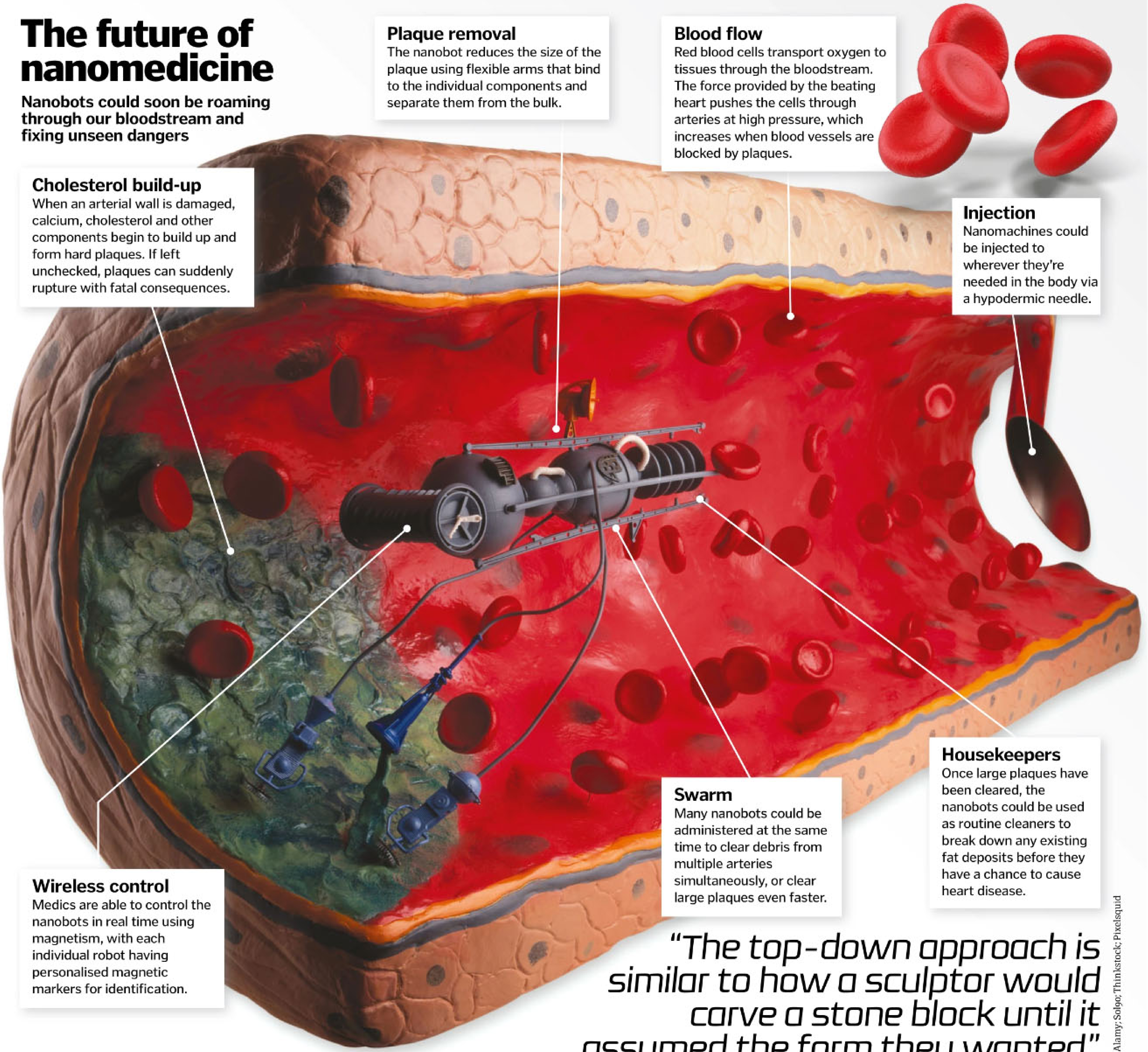
The movie *Fantastic Voyage* told the story of a submarine holding a small crew that had been shrunk down so small they could be inserted into the bloodstream. Their mission: to clear a blood clot that was lurking inside their human host. The story seemed impossible at the time, but today we are busily working toward our own mini-medics to help heal us from the inside.

Medical nanobots are one of the most ambitious areas of nanotechnology. The aim is to create tiny, controllable robots that can navigate through the bloodstream to reach places we currently find hard to reach, and repair damage without the need for invasive surgery. They could break down hard plaques found on arterial walls or clear blood clots in the brain.

Nanobots could perform surgery on individual cells, minimising the damage to healthy tissue

The future of nanomedicine

Nanobots could soon be roaming through our bloodstream and fixing unseen dangers



Plaque removal
The nanobot reduces the size of the plaque using flexible arms that bind to the individual components and separate them from the bulk.

Blood flow
Red blood cells transport oxygen to tissues through the bloodstream. The force provided by the beating heart pushes the cells through arteries at high pressure, which increases when blood vessels are blocked by plaques.

Cholesterol build-up
When an arterial wall is damaged, calcium, cholesterol and other components begin to build up and form hard plaques. If left unchecked, plaques can suddenly rupture with fatal consequences.

Injection
Nanomachines could be injected to wherever they're needed in the body via a hypodermic needle.

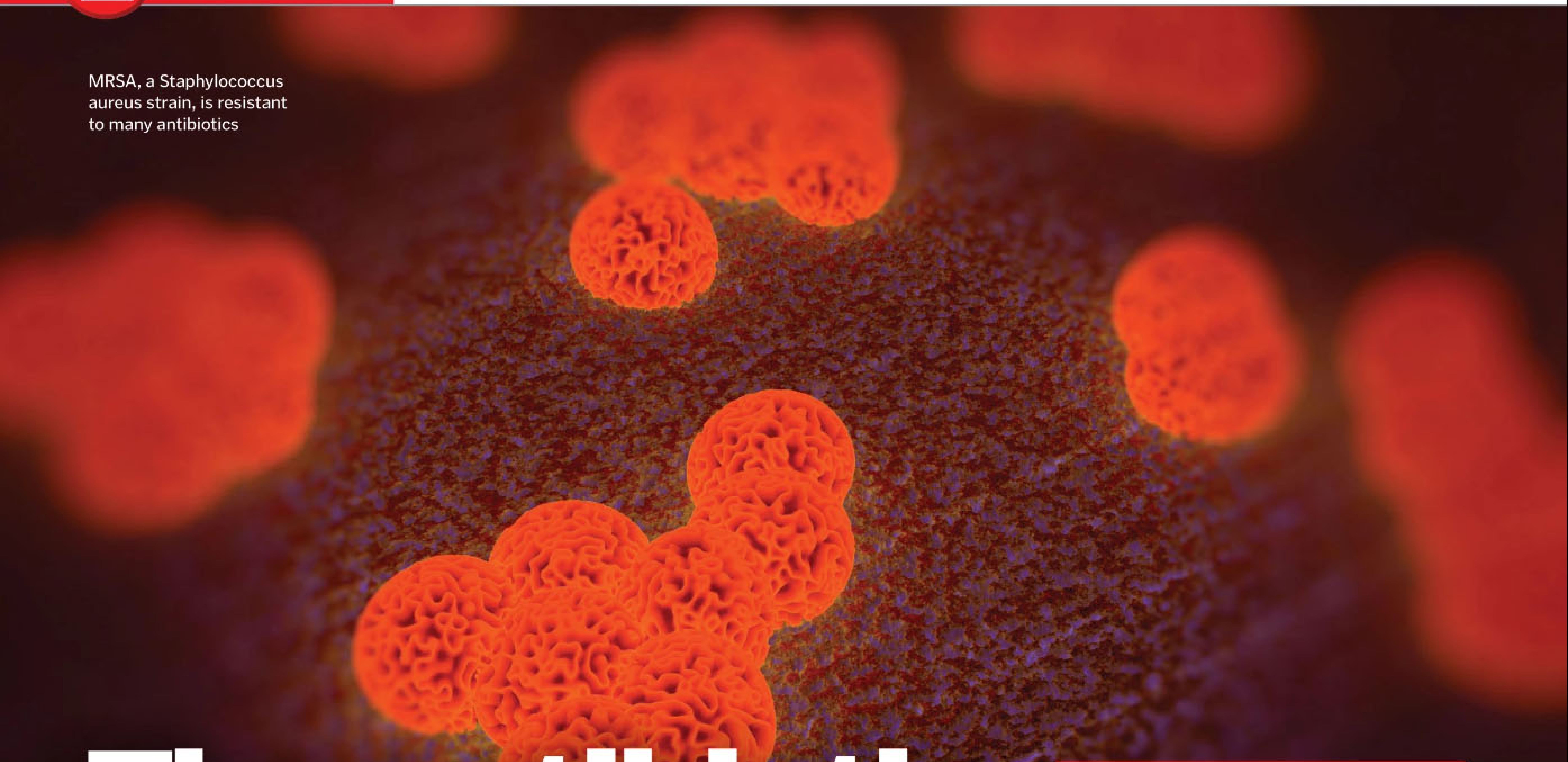
Wireless control
Medics are able to control the nanobots in real time using magnetism, with each individual robot having personalised magnetic markers for identification.

Swarm
Many nanobots could be administered at the same time to clear debris from multiple arteries simultaneously, or clear large plaques even faster.

Housekeepers
Once large plaques have been cleared, the nanobots could be used as routine cleaners to break down any existing fat deposits before they have a chance to cause heart disease.

> *"The top-down approach is similar to how a sculptor would carve a stone block until it assumed the form they wanted"*

© Alamy; Solgo; Thinkstock; Pixelsquid



MRSA, a Staphylococcus aureus strain, is resistant to many antibiotics

The antibiotic apocalypse

Are we heading towards a future where infections are immune to treatment?

We have a major problem. Since the dawn of humanity, we have been locked in a battle with microscopic organisms, and just when we thought we were starting to win, they're fighting back.

Bacteria cause some of the most devastating human diseases, from typhoid fever to tuberculosis, and until the 1920s, we were utterly defenceless. But when Alexander Fleming ushered in the age of the antibiotic with his discovery of penicillin, we suddenly had a powerful weapon.

Antibiotics work by stopping bacteria from dividing, or by killing them outright. Thanks to them we can treat infections that were once fatal, we can perform complex surgery, and we can mass-produce food on an unprecedented scale. But we have used them and used them and used them, and the bacteria have started to learn.

These little organisms can replicate in a matter of hours, and each time they do, they make tiny, accidental tweaks to their genetic code. Some tweaks aren't useful, but very occasionally, a mistake is made that helps one bacterium to outlast an onslaught of antibiotics for just a little longer than their neighbours.

When the course of antibiotics are finished, and all of the vulnerable bacteria are dead, this slightly stronger individual can carry on dividing, making a new colony that are all a little bit better at avoiding the effects of the drugs. And if this happens time after time, you have a superbug on your hands.

Worse still, bacteria are able to share useful genes with their neighbours. And not just members of their own species. They carry useful snippets of genetic code in little rings of DNA called plasmids, and they can swap these like trading cards, passing resistance on to others around them.

Using these tactics, several strains of bacteria are now able to evade almost all of the antibiotics in our arsenal. We're in the middle of a microscopic arms race, and the future of medicine is hanging in the balance.

Antibiotics are used everywhere, from hospitals to intensive farms

What needs to be done?

Ensuring that effective antibiotics are available for future generations is a mammoth task. We need to stop giving bacteria the opportunity to see our best treatments.

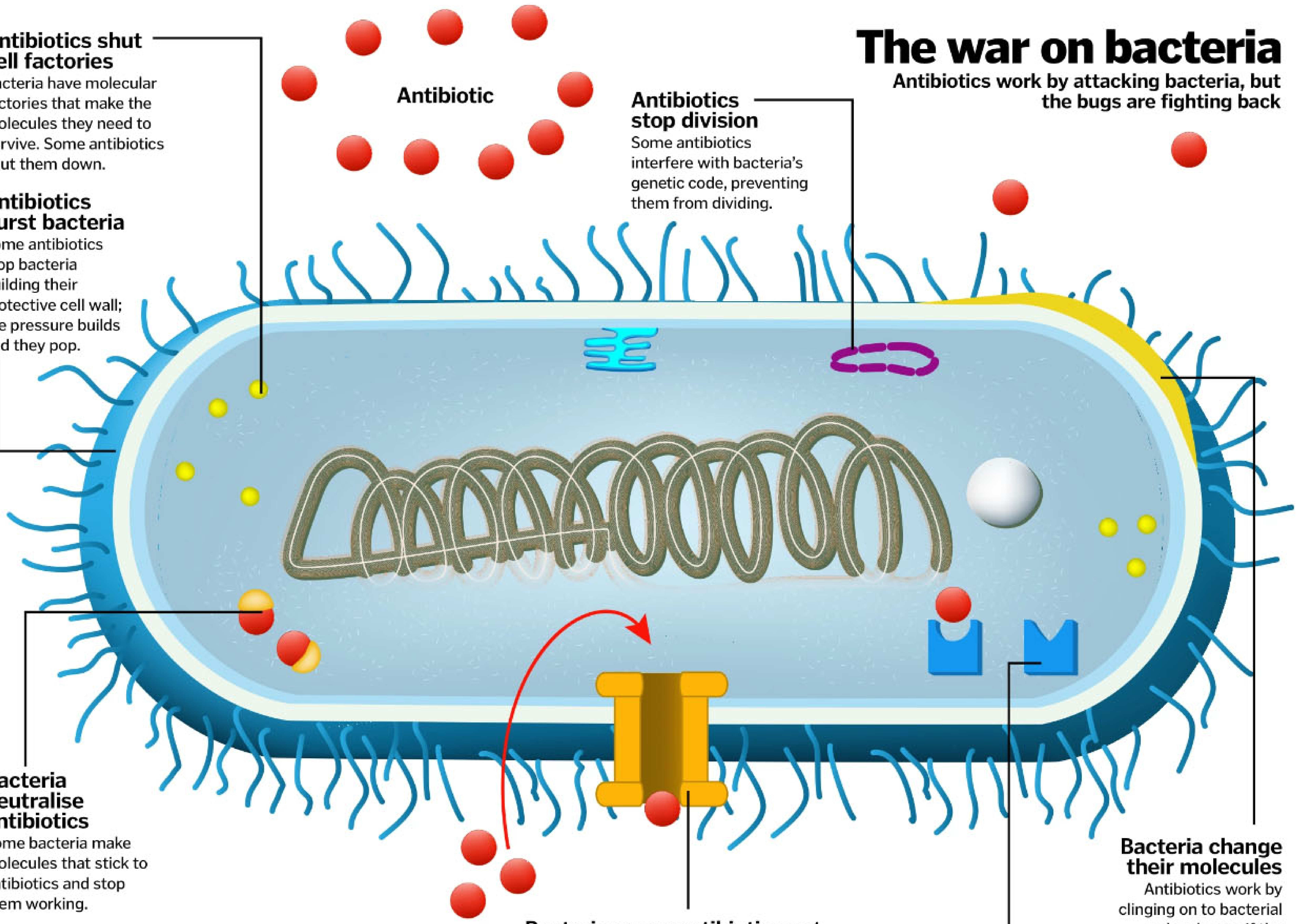
Vets and doctors are being urged to only use antibiotics if absolutely necessary, and to test their patients beforehand to check that the treatment will definitely work to kill the infection. Patients are being asked to always finish their full course of antibiotics, even if they feel better, to ensure that any lurking bacteria have been cleared up. Farmers are being encouraged to keep their livestock clean and vaccinated rather than use antibiotics to control disease. Governments and development organisations are under pressure to regulate and monitor antibiotic use, and to make sure people have access to the right antibiotics. And the medical research community are racing to find new drugs to fight resistant strains.

Rather than throw antibiotics at any infection, we need to choose our battles carefully.

DID YOU KNOW? *The first antibiotic, penicillin, was discovered by accident when a blob of mould got into an experiment*

The war on bacteria

Antibiotics work by attacking bacteria, but the bugs are fighting back



Antibiotics shut cell factories
Bacteria have molecular factories that make the molecules they need to survive. Some antibiotics shut them down.

Antibiotics burst bacteria
Some antibiotics stop bacteria building their protective cell wall; the pressure builds and they pop.

Antibiotics stop division
Some antibiotics interfere with bacteria's genetic code, preventing them from dividing.

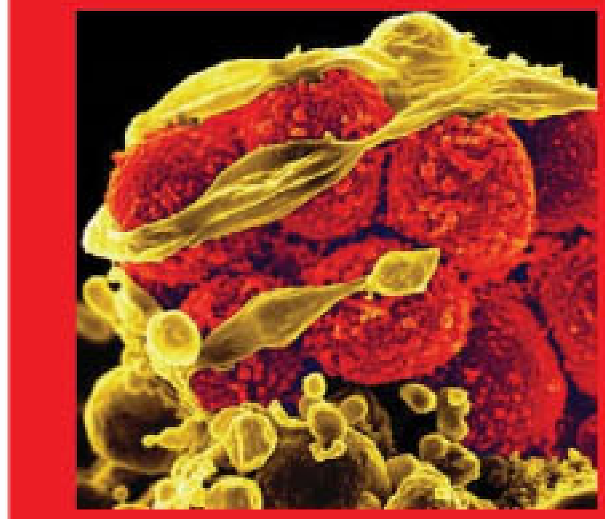
Bacteria neutralise antibiotics
Some bacteria make molecules that stick to antibiotics and stop them working.

Bacteria pump antibiotics out
If antibiotics do get inside bacteria, some are able to pump them straight out again.

Bacteria change their molecules
Antibiotics work by clinging on to bacterial molecules, so if the bacteria can change their shape, they can sometimes escape.

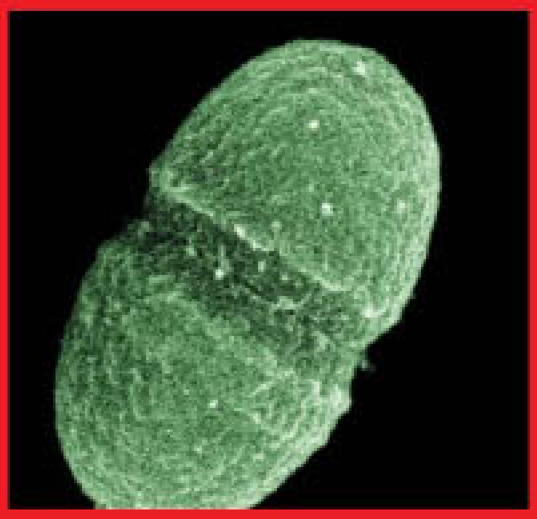
Bacteria block antibiotic entry
Some bacteria have developed ways to stop antibiotics from getting through their cell walls.

Superbug lineup



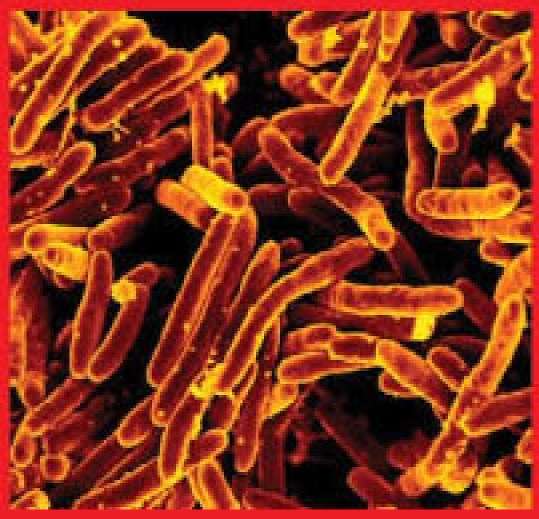
MRSA

Methicillin-resistant Staphylococcus aureus (MRSA) is the most infamous of all superbugs. Regular Staphylococcus aureus is a common type of bacteria, normally found harmlessly on the skin. This bug first started resisting the effects of antibiotics as far back as the 1950s, however, and MRSA itself first appeared in 1962.



VRE

Vancomycin-resistant Enterococcus (VRE) are immune to the effects of one of our most powerful antibiotics. Vancomycin is usually reserved for the most serious of infections, including meningitis and MRSA. These superbugs were first spotted in the 1980s, and have proven very good at developing resistance to any new antibiotics thrown at them.



MDR-TB

Multi-drug-resistant Mycobacterium tuberculosis (MDR-TB) does not respond to the two most powerful anti-tuberculosis drugs currently available - rifampicin and isoniazid. Normal treatment for TB involves a combination of antibiotics taken for 6 months, but if the drugs are given alone, or stopped too soon, resistance can develop.

KPC

Klebsiella pneumoniae carbapenemase-producing bacteria (KPC) are a relatively new problem, first identified in the USA in the early 2000s. They are very good at resisting treatment, and also produce an enzyme that allows them to break down carbapenem, a powerful antibiotic that's one of our last lines of defence.

Learn more

Arm yourself with information
Knowledge is the most powerful weapon we have against an antibiotic apocalypse, here are two top places to learn more:

- **The World Health Organisation**
  www.who.int
  Working in over 150 countries, the World Health Organisation are leading the fight against antibiotic resistance. Their social media accounts are a great place for bite-sized news and updates.

- **Bugs and Drugs**
  www.antibioticresistance.org.uk
  With funding from the British Government's Department of Health, the National Electronic Library of Infection have made a one-stop hub of information about antibiotic resistance.

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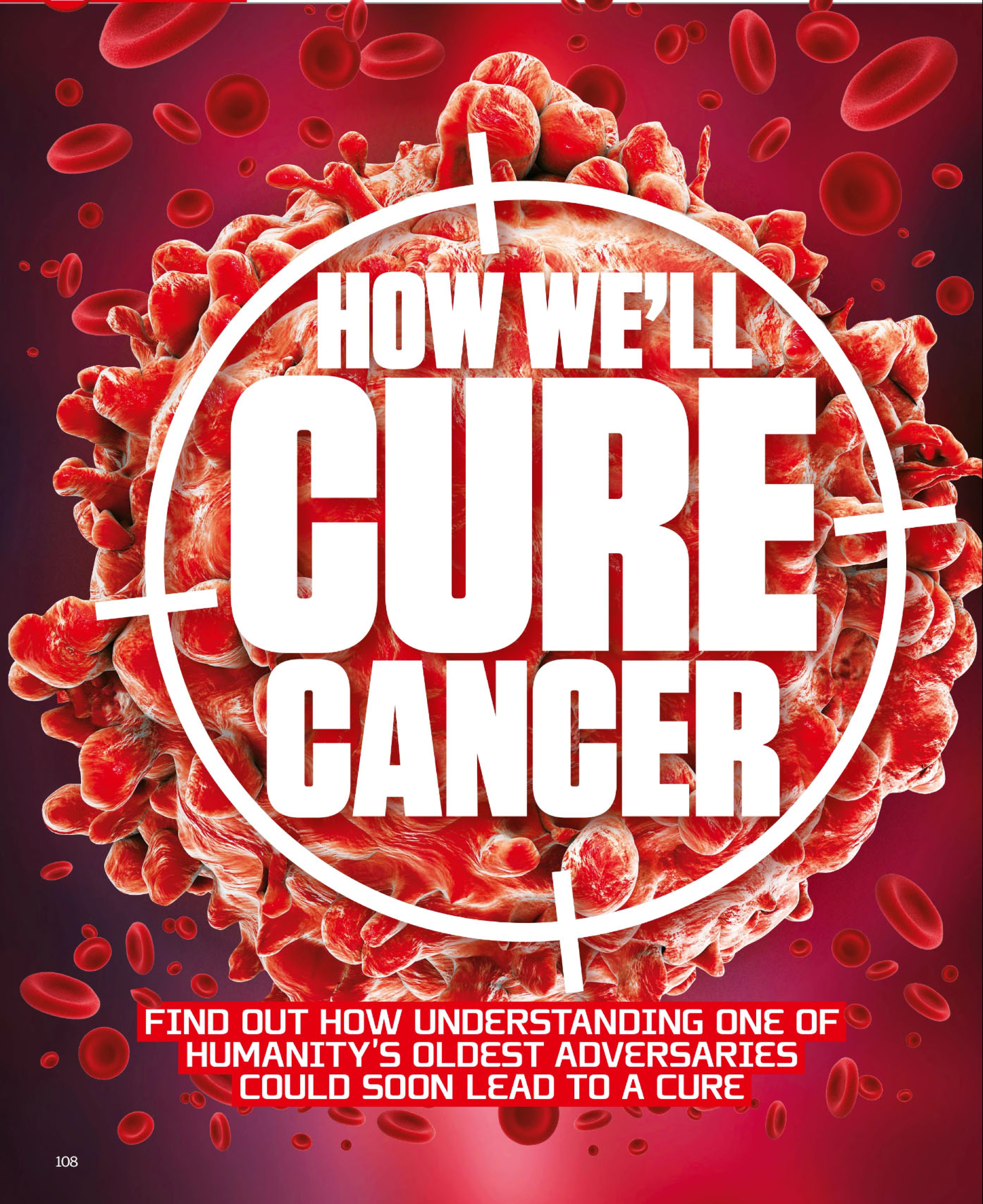


HOW WE'LL CURE CANCER

FIND OUT HOW UNDERSTANDING ONE OF HUMANITY'S OLDEST ADVERSARIES COULD SOON LEAD TO A CURE

DID YOU KNOW? *Hippocrates named cancer 'Karkinos' after the giant mythical crab due to the way tumours look as they spread*

Cancer has been around longer than we have. Traces have been found in 70 million-year-old dinosaur bones, in a 120,000-year-old Neanderthal rib, and in a human skeleton dating back to 1200 BCE. And almost every animal, even sharks and naked mole rats, can get the disease.

It was once untreatable. Ancient Roman doctor Celsus wrote, "After excision, even when a scar has formed, none the less the disease has returned." Even if the tumours were removed, they kept coming back, but in ancient times we didn't fully understand exactly what we were up against.

By the 17th century, physicians were pointing the finger at a straw-coloured liquid called lymph, which passes through the body in channels that run alongside the blood vessels. And by the mid-1800s, it became clear that cancers were actually made from cells.

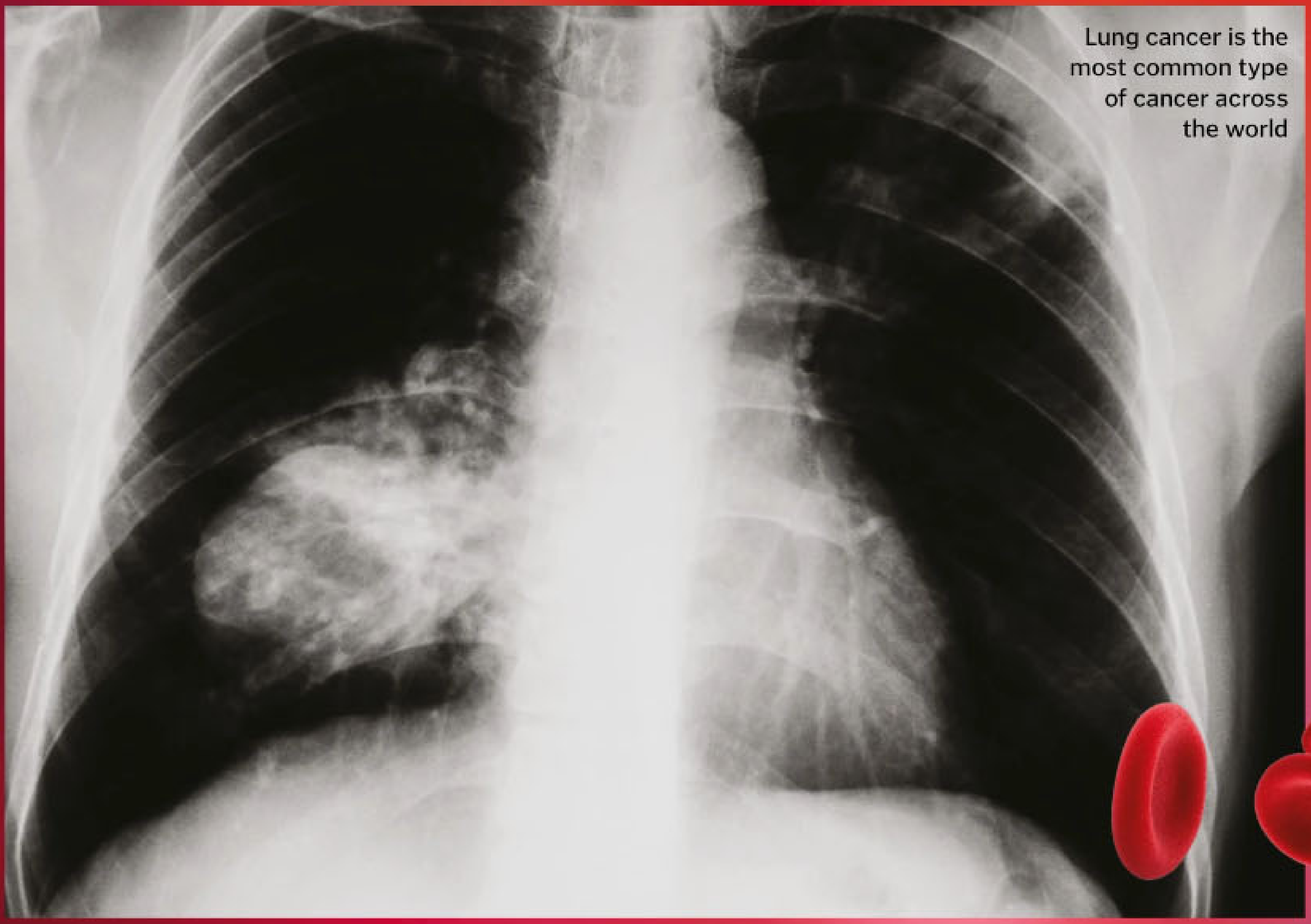
Realising that cancer spread from the original tumour, 19th-century surgeons, with the help of new anaesthetics, started removing more tissue and nearby lymph nodes. Then, at the start of the 20th century, radiotherapy became available to treat irremovable cancers. Nitrogen mustards then became the first chemotherapy drugs after WWI.

Then a massive breakthrough was made. In 1953, James Watson and Francis Crick deciphered the structure of DNA, opening the door to a new era of genetic science. We now know that tumours are made of our own cells but their genes have gone wrong. They change constantly, they evolve to escape treatments, and they hide and spread undetected. And the more we learn, the more we are unravelling their weaknesses.

A century ago a cure for cancer would have been unthinkable, but as research continues survival is rising, and there are many more discoveries yet to be made.

> *"Watson and Crick deciphered the structure of DNA"*

Damage builds up in our DNA over time, making cancer more common in older people



Lung cancer is the most common type of cancer across the world

Cancer statistics

14 million
people were diagnosed with cancer in 2012

22%
of cancer deaths are caused by smoking

8.2 million
people died from cancer in 2012

70%
of cancers happen in low and middle income countries

Cancer is the second highest cause of death in the world

Up to half of all cancers can be prevented by lifestyle changes

Lung cancer is the most common worldwide, followed by breast and colon

The UK has the 23rd highest cancer rate in the world

© Getty; Thinkstock

What is cancer?

The first step to finding a cure is understanding exactly what we're up against

You're made up of an estimated 37.2 trillion cells, each containing an entire copy of your DNA, which consists of 23 pairs of chromosomes and 21,000 genes, written in combinations of four chemical 'letters': A, C, G and T.

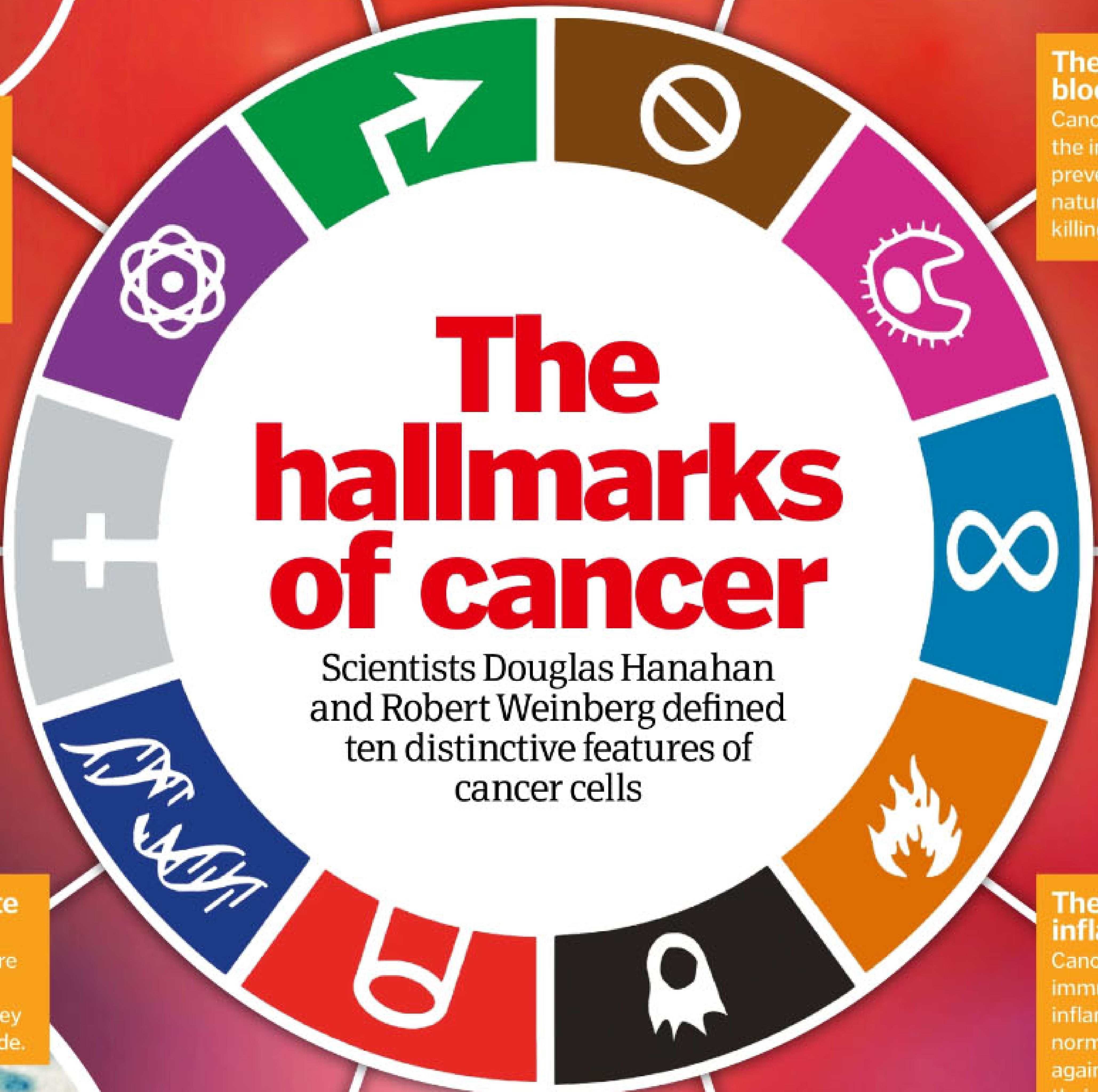
The full human DNA sequence contains around 3 billion letters, and the genes are arranged into three-letter 'words' called codons. Each word corresponds to a molecular building block called an amino acid and, when genes are read in order, the words in a gene provide the recipe to build a protein. Proteins are crucial for everything that a cell does, from making energy to deciding when to divide to communicating with its neighbours. But in cancer cells vital genes contain mistakes, changing their proteins and altering the way that they behave.

It takes lots of genetic mistakes to turn a healthy cell into a cancer cell, and they tend to build up over time. A few people inherit genetic faults from their parents, but most occur as we get older. Sunlight, alcohol, radiation and smoking, for example, can all cause harm to our genetic code. But even people with the healthiest lifestyles accumulate genetic faults.

Cells divide for growth and repair, making copies of themselves to replace old cells or to heal wounds. In order to do this, a cell must first duplicate all 3 billion letters of its DNA, and doing this without making a single mistake is a virtually impossible task.

The copied code is scanned for errors, and mistakes are usually fixed before the cell

> "Cancer cells keep making copies of themselves with more mistakes"



The hallmarks of cancer

Scientists Douglas Hanahan and Robert Weinberg defined ten distinctive features of cancer cells

They keep growing
Cells normally wait for a signal to divide, but cancer cells make their own growth signals.

They don't stop when told
Cancer cells ignore signals telling them to stop dividing.

They avoid white blood cells
Cancer cells hide from the immune system, preventing the body's natural defences from killing them.

They are immortal
Normal cells stop dividing when they become old, but cancer cells keep on replicating indefinitely.

They create inflammation
Cancer cells hijack immune cells, using inflammation that would normally help to fight against an infection to their own advantage.

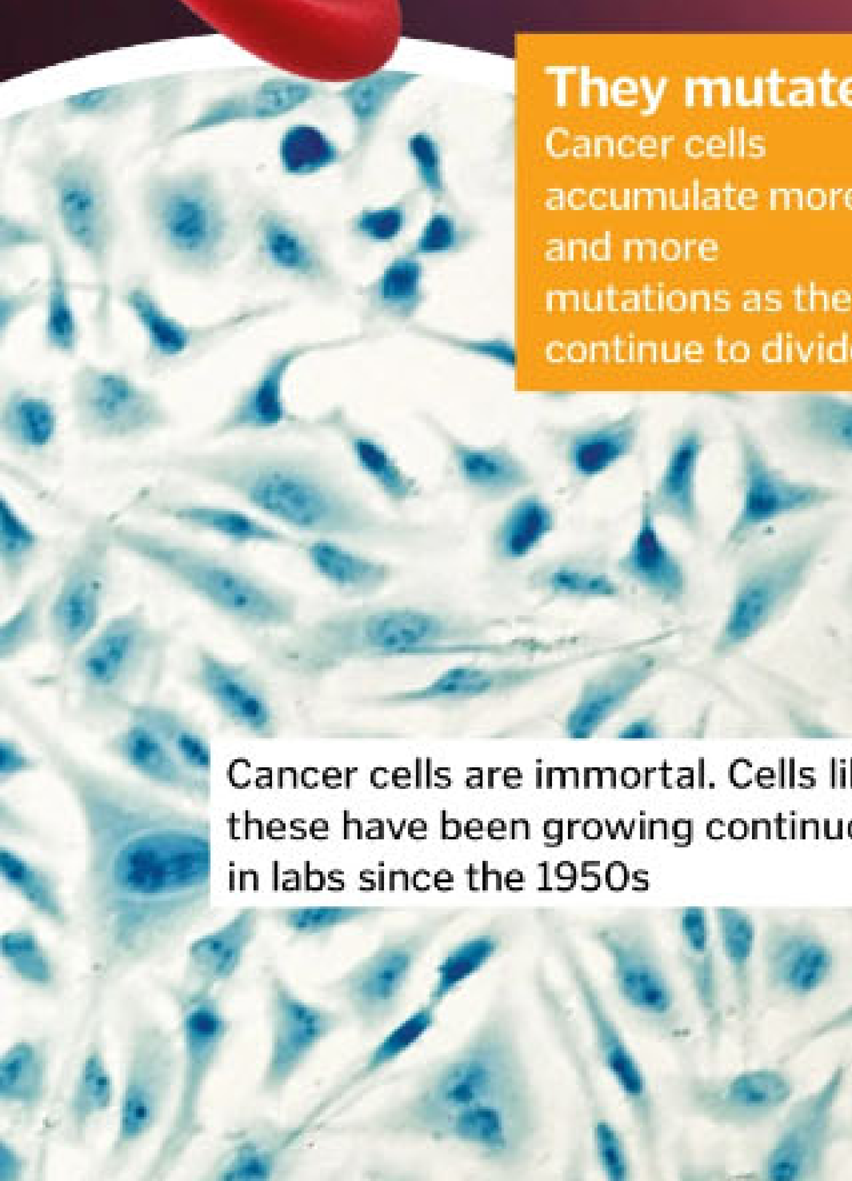
They spread
Cancer cells can spread around the body, creating more tumours in other places.

They set up fuel lines
As tumours grow, they get more oxygen and nutrients by encouraging new blood vessels to form.

They mutate
Cancer cells accumulate more and more mutations as they continue to divide.

They resist death
Healthy cells self-destruct when they are damaged, but cancer cells turn this safety switch off.

They change their metabolism
Cancer cells reprogram their metabolism to keep dividing under conditions that would normally kill other cells.



Cancer cells are immortal. Cells like these have been growing continuously in labs since the 1950s

DID YOU KNOW? *Cancer is not contagious, but some viruses, like hepatitis B, HIV and HPV, can cause cancer by damaging DNA*

divides, but sometimes errors slip through and over time they start to build up.

Just as changing the letters in a book would make the words unreadable, changing the letters in the genetic code makes it hard for the cell to make sense of its genes. If letters are changed, deleted, added or moved around, it can completely change the meaning of the genetic words, which in turn changes the proteins that the cell makes.

Built-in safety mechanisms normally tell a cell to self-destruct if it has too many genetic errors, allowing a new, healthy cell to take its place. But sometimes damaged cells slip through the net, failing to repair themselves and resisting the signals to die.

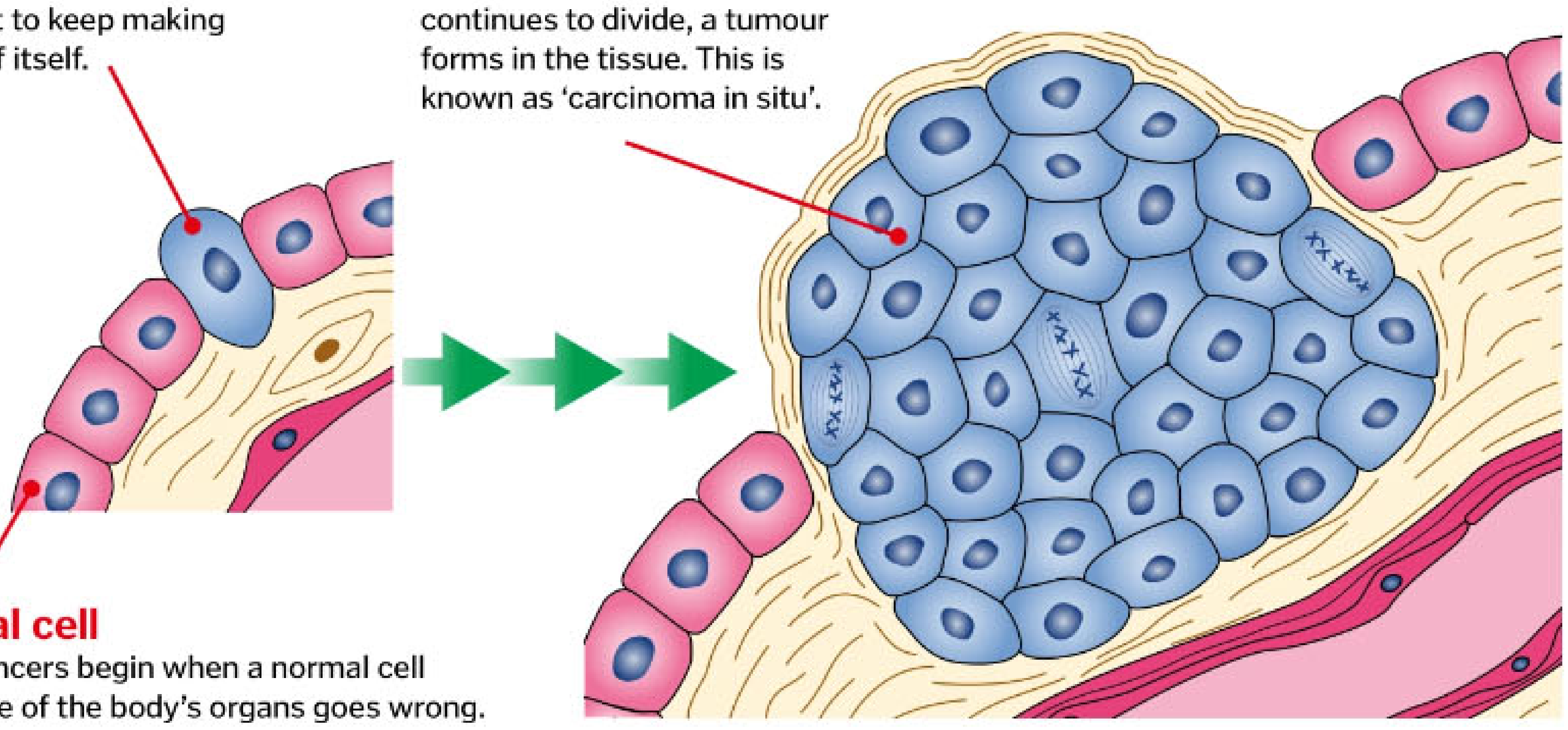
Cancer cells tend to have errors in genes known as 'oncogenes' or 'tumour suppressor genes'. Oncogenes are normally responsible for telling healthy cells to divide, helping with growth and wound repair, but mutations in cancer can cause them to become permanently switched on. Tumour suppressor genes, on the other hand, tell cells to stop dividing once growth or repair is completed, and errors in these genes can cause them to turn off. The result is that the damaged cells divide and divide and divide, piling up on top of each other to form a tumour.

With their safety systems switched off and nothing to tell them to stop, cancer cells keep making copies of themselves with more mistakes in their genetic code, and this leads to Darwinian evolution at a rapid speed. Just as if a wild animal has a beneficial genetic trait it will be more likely to reproduce, if a cancer cell has a beneficial trait it will be more likely to survive.

Cancer cells forget what they are supposed to be doing and gain new abilities, developing traits that allow them to hide from the immune system, survive on less oxygen, and even evade chemotherapy. But, most dangerous of all, they gain the ability to move through the body, spreading to distant places via the blood or lymphatic systems and making new tumours elsewhere. But the more we understand about how cancer works, the better we are becoming at treating it.

How cancer starts

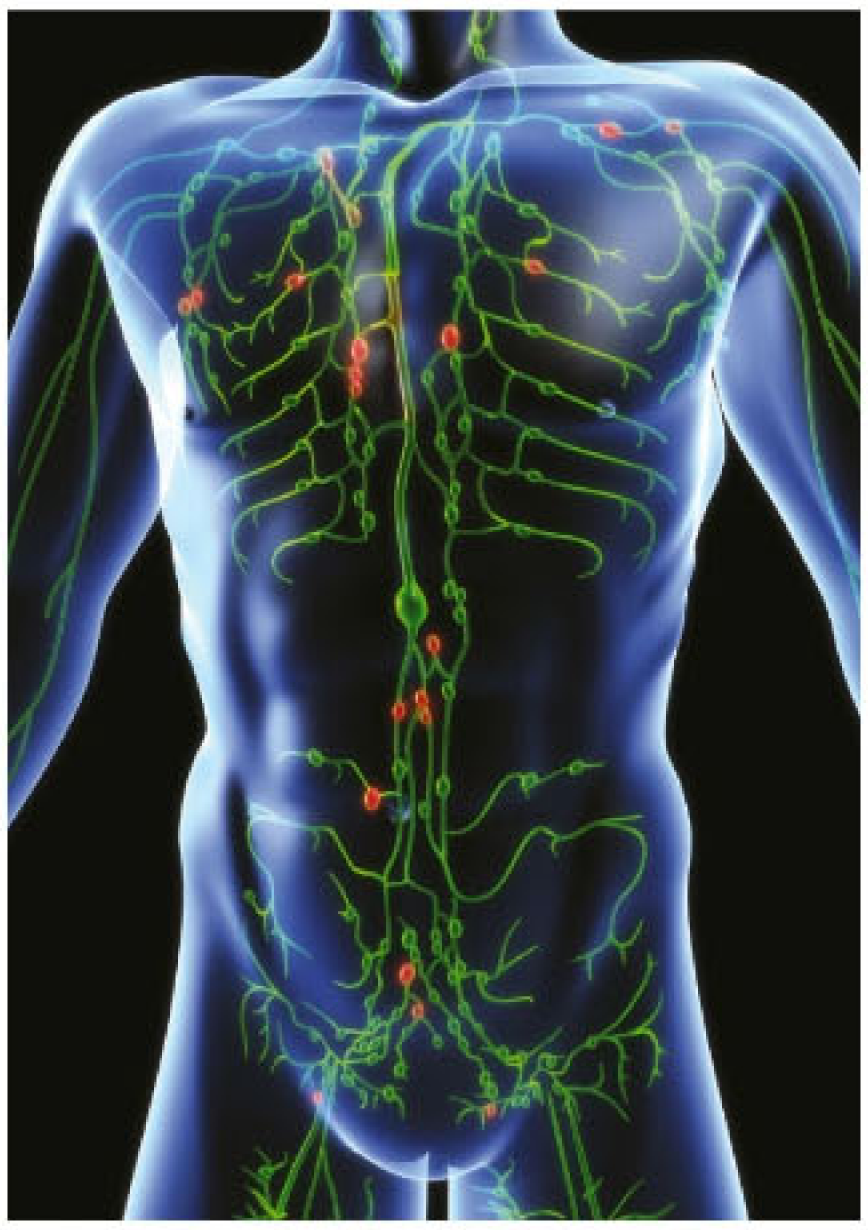
Cancer begins with a single mutated cell that divides and spreads



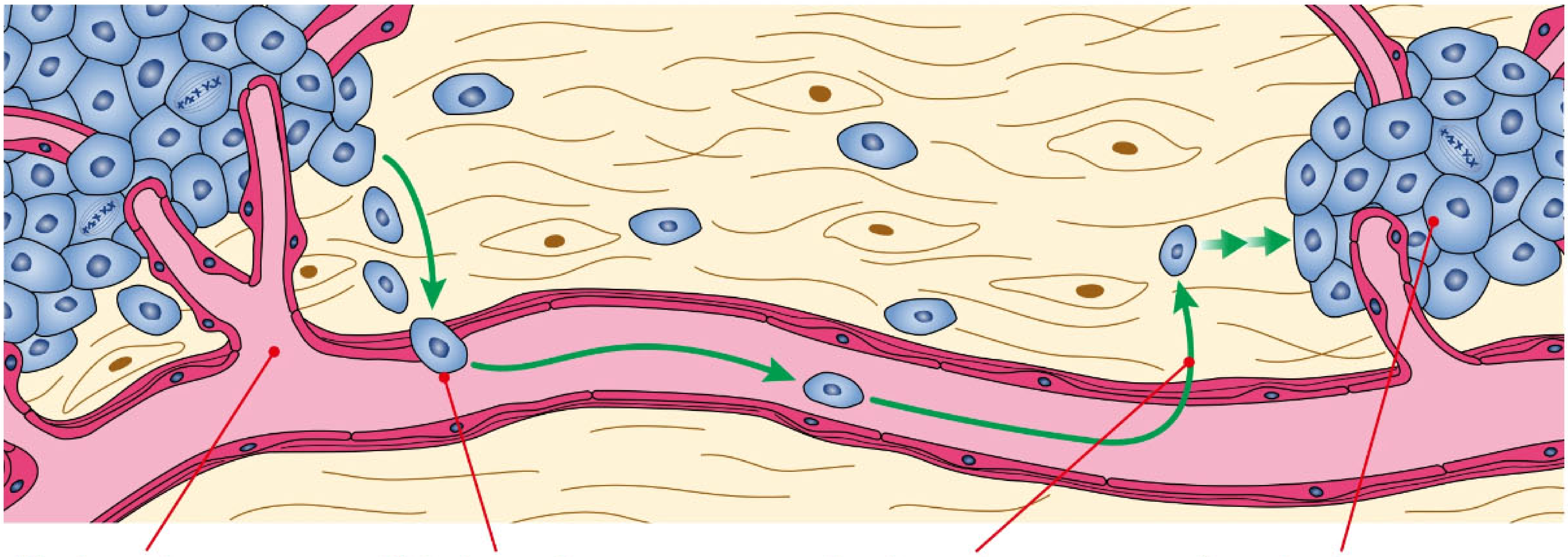
Cancer cell
Genetic errors inside the cell tell it to keep making copies of itself.

Tumour
As the abnormal cell continues to divide, a tumour forms in the tissue. This is known as 'carcinoma in situ'.

Normal cell
Most cancers begin when a normal cell lining one of the body's organs goes wrong.



Cancer cells can use the lymphatic system to spread around the body



Blood vessels
To keep growing the tumour needs a blood supply, so it encourages the formation of new blood vessels.

Distant spread
Cells start to break away from the main tumour, entering the lymphatic system and the blood vessels and spreading around the body.

Local spread
Eventually, the tumour starts to invade the local tissue, growing down into the connective tissue below.

Secondary tumour
Cancer cells become lodged in different tissues and continue growing, forming more tumours known as 'secondaries' or 'metastases'.

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Treating cancer

There are three major types of cancer treatment: surgery, radiotherapy and chemotherapy

Chemotherapy

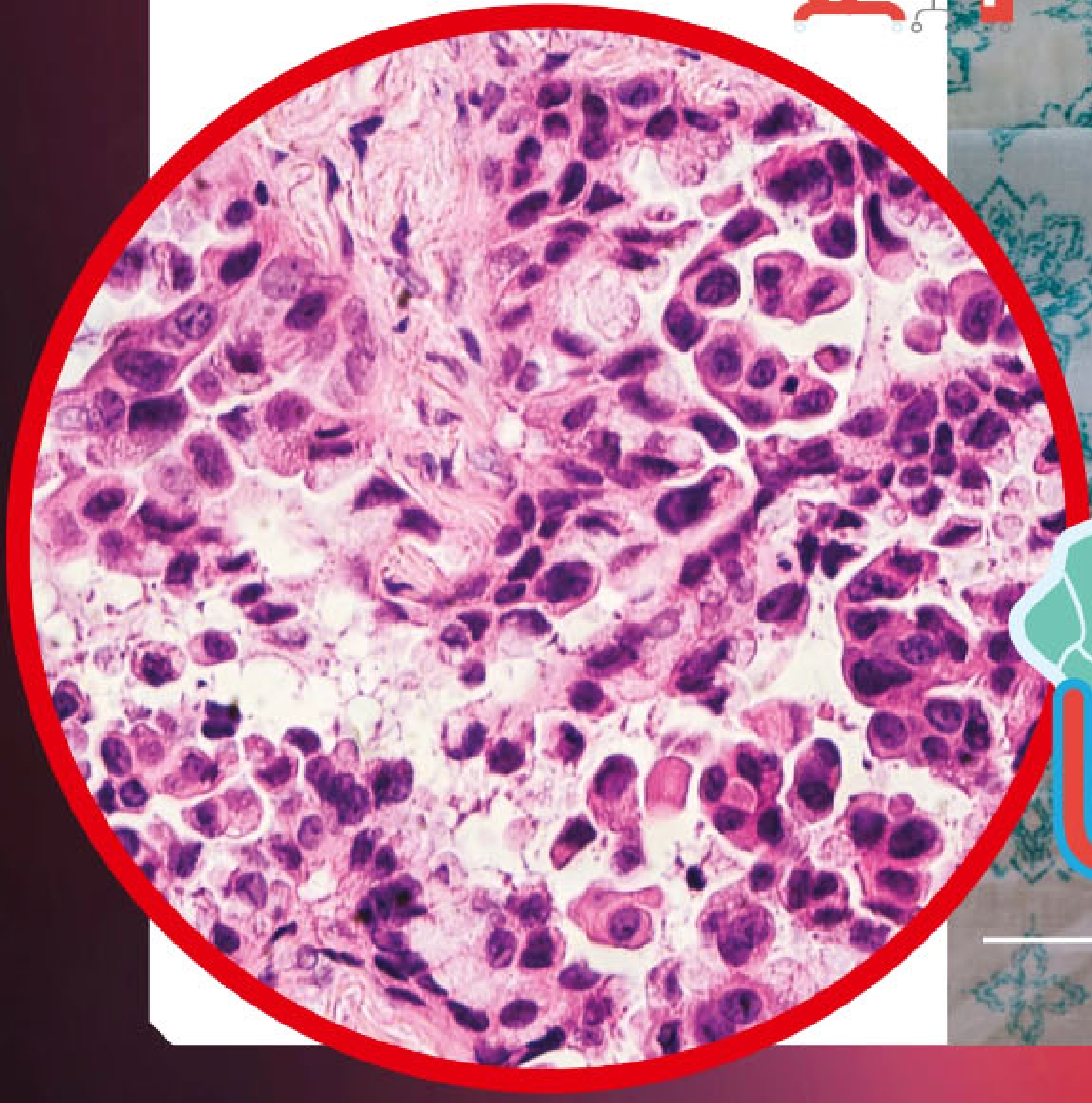
The first chemotherapy drug was developed using mustard gas, a chemical weapon used during WWI. Scientists had noticed that the poison killed the fast-dividing cells of the bone marrow, and so they adjusted the weapon to make nitrogen mustard, a treatment that could kill rapidly replicating cancer cells.

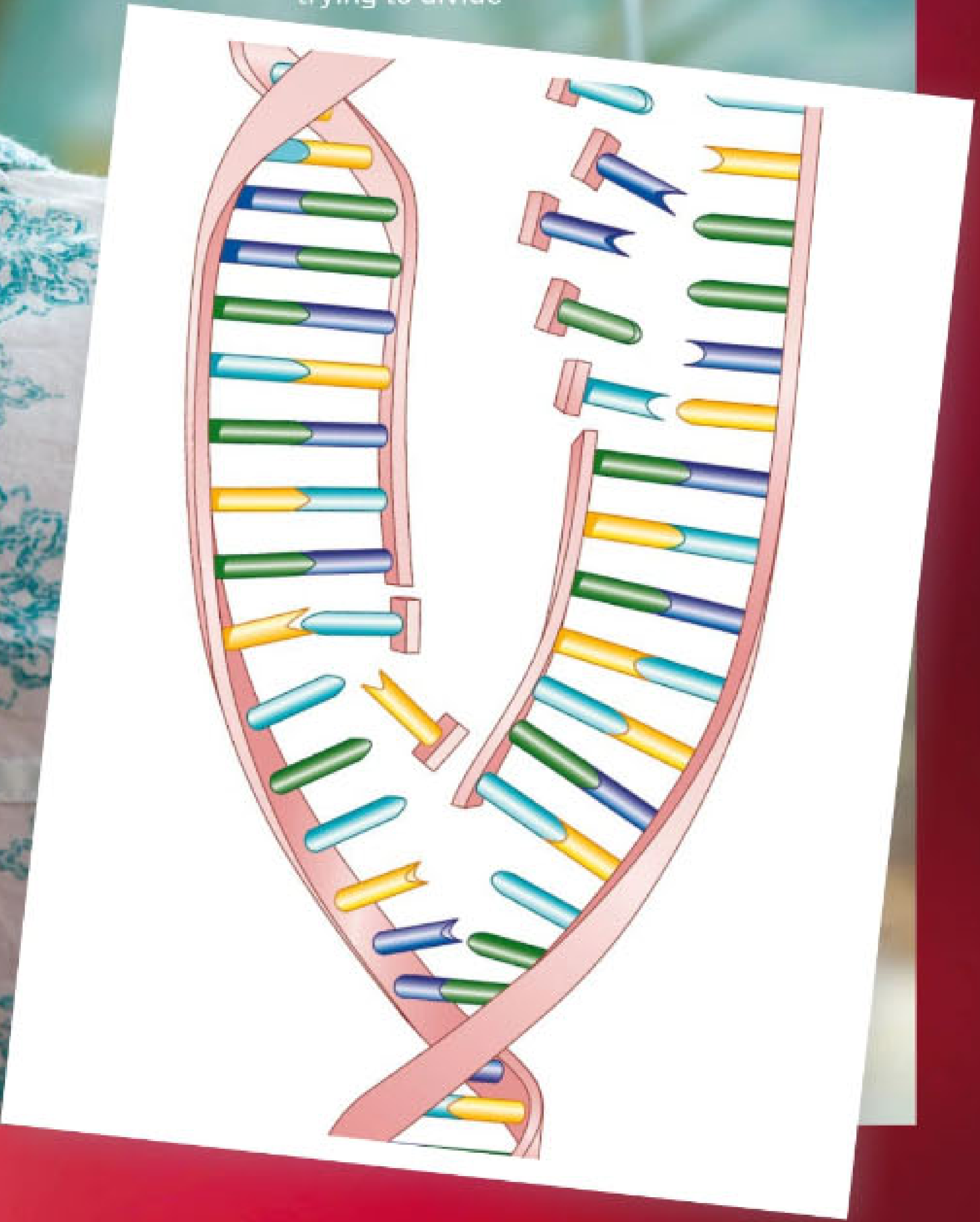
Nitrogen mustard belongs to a group of drugs known as alkylating agents, which work by adding chemical units called alkyl groups to DNA. These interfere with the double helix structure, causing the genetic code to break apart.

Other chemotherapies work in similar ways. Heavy metals cross-link DNA, preventing it from being read. Topoisomerase inhibitors stop the DNA helix from unwinding, and antimetabolites work by mimicking molecules involved in copying DNA, stopping the new sequence from being made. Anti-microtubule, or spindle poisons, stop cells from splitting apart, and cytotoxic antibiotics stick to the DNA helix, prevent unwinding, link different strands of DNA together or break DNA into fragments.

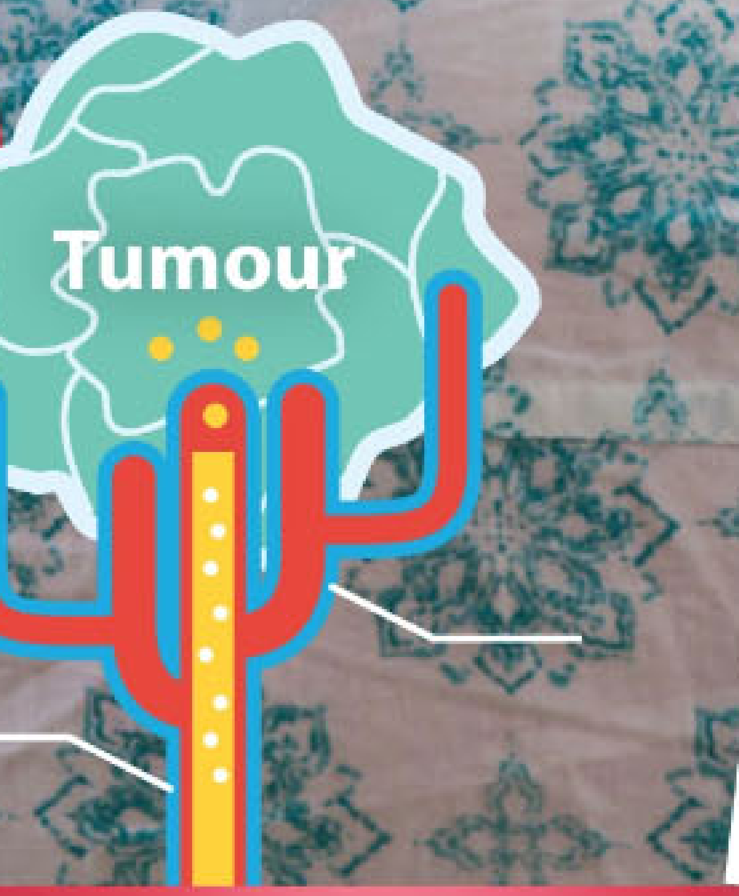
These treatments are particularly harmful to cells that are trying to make copies of themselves because they target DNA replication and cell division. This is good for catching fast-dividing cancer cells, but it isn't perfect. Cancer cells aren't always dividing, so some cells manage to escape the treatment, and lots of healthy cells also divide rapidly, too. Hair, skin and bone marrow (which makes blood cells) are all damaged by chemotherapy, leading to side-effects like hair loss, sickness and a weakened immune system.

Pathologists examine images like these to diagnose cancer. This lung tissue should be full of holes





Chemotherapies harm cells that are trying to divide



DID YOU KNOW? *Around half of cancer patients receive radiotherapy. It is the most effective cancer treatment after surgery*

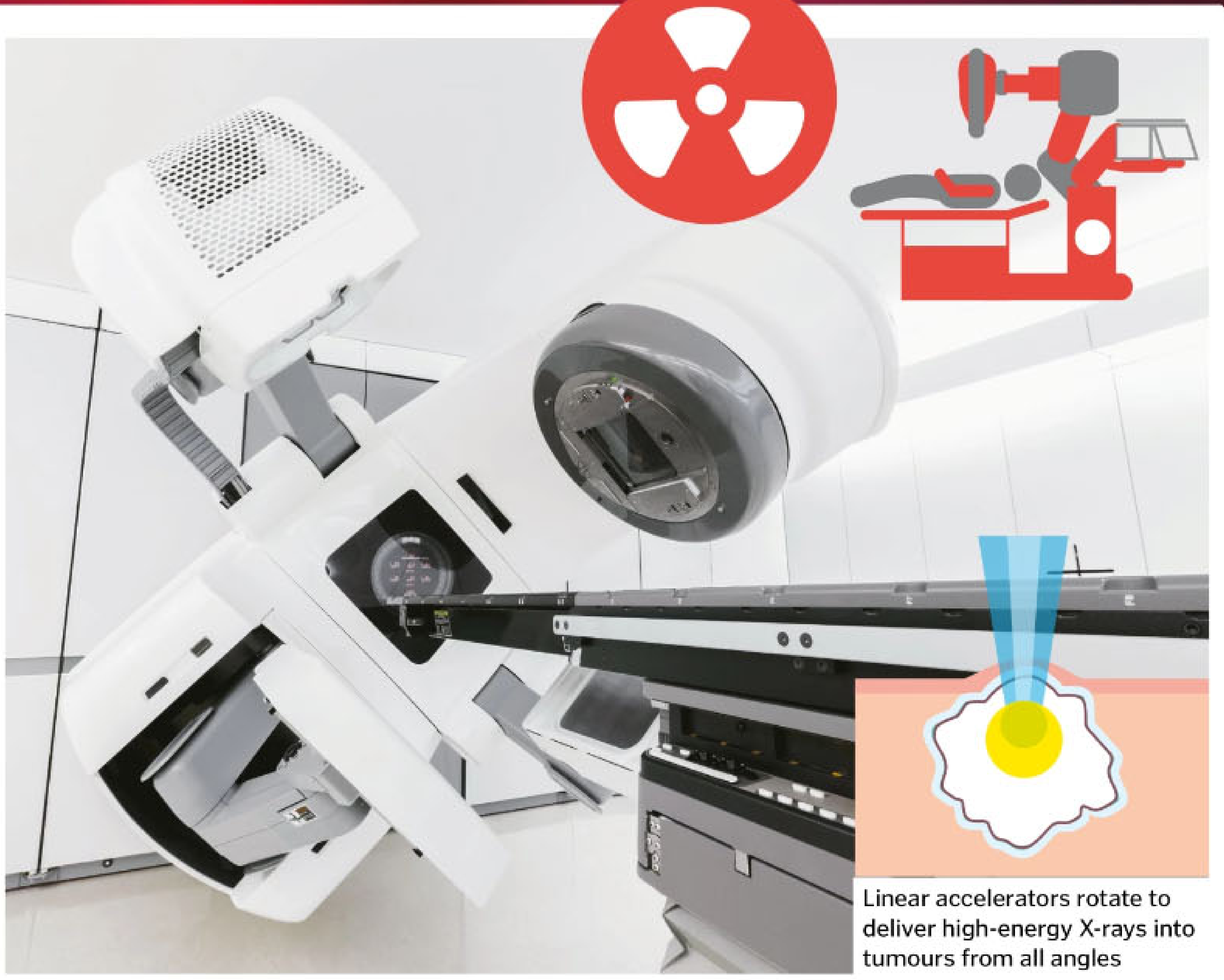
Radiotherapy

Radiotherapy was developed in the early 20th century and works by bombarding cancer cells with radiation. When the water molecules inside the cells are hit they split apart in a process called radiolysis. This makes highly reactive free radicals with an unpaired electron that attacks bonds belonging to other molecules, setting off a chain reaction that damages DNA.

Radiotherapy causes both strands of the DNA to break close together, a lesion known as a 'double-strand' break. This makes the helix unstable and it starts to unwind. Cells can repair a bit of this kind of damage, but the more radiation they receive, the more likely they are to die.

The most common way to deliver radiotherapy is by using a linear accelerator (LINAC). It uses microwaves to make electrons, which hit a heavy metal to make X-rays. CT or MRI scans are used to pinpoint the exact location of the tumour inside the body, and the X-rays are then shaped to fit the outline of the tumour. This is done by blocking part of the beam using sheets of metal known as a multileaf collimator.

X-rays go all the way through the body, so the machine rotates to deliver beams from all angles, giving the maximum dose where the beams cross over at the site of the tumour, minimising the amount of radiation received by the surrounding healthy tissue.



Linear accelerators rotate to deliver high-energy X-rays into tumours from all angles

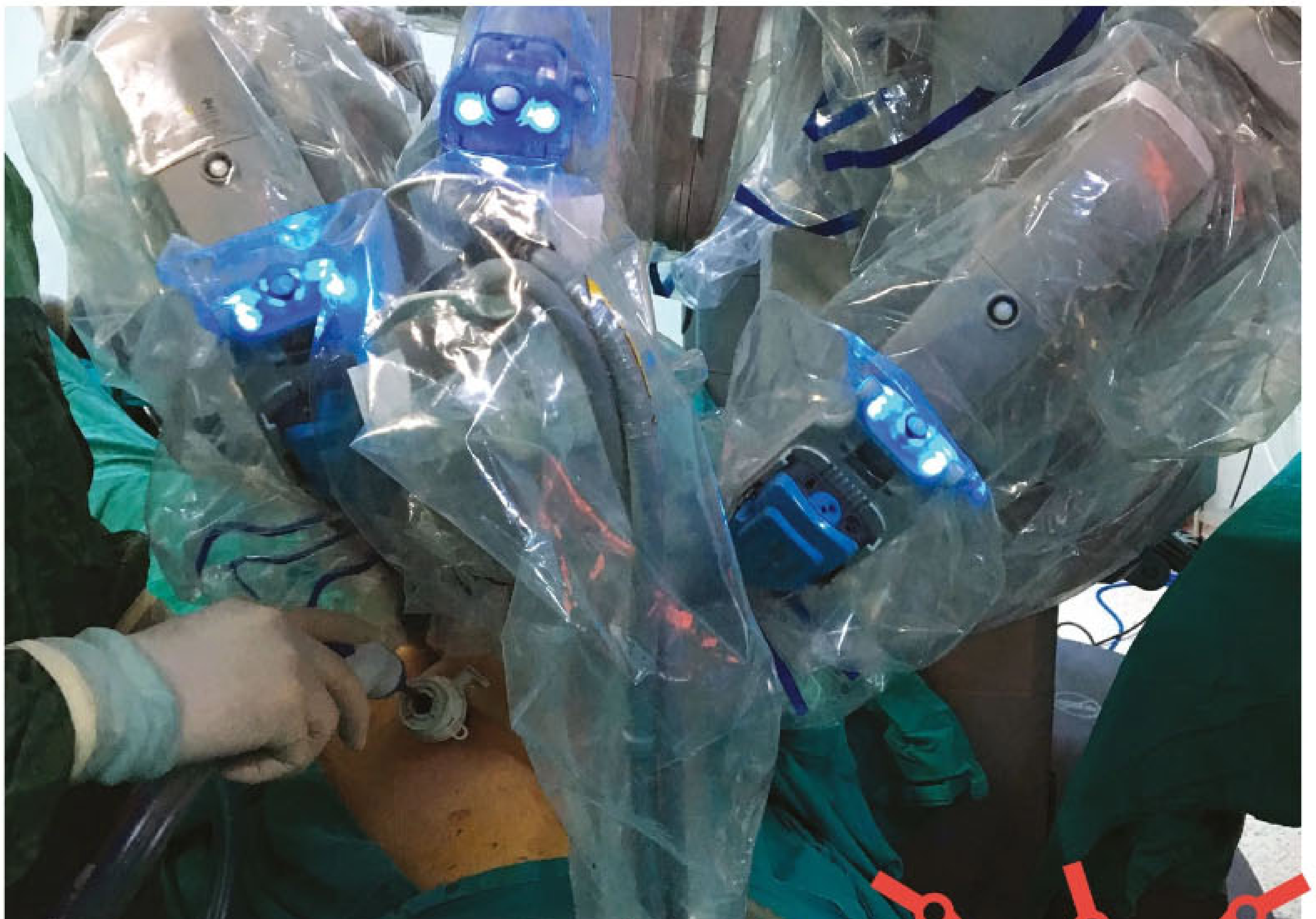
Surgery

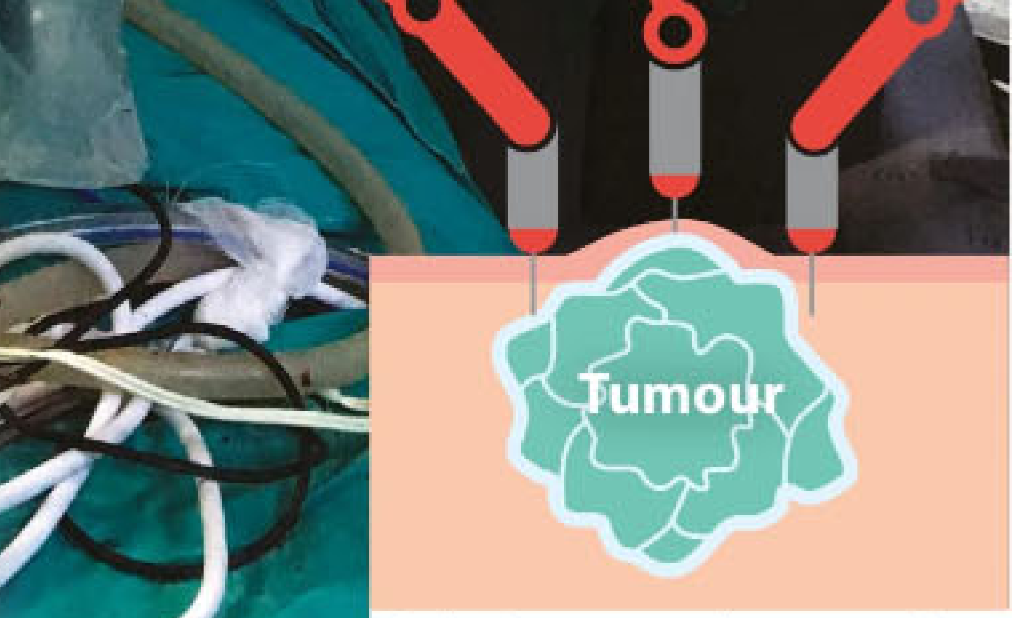
Surgery is one of the oldest and most effective cancer treatments. If the cancer hasn't spread, surgeons take out the whole tumour and some of the surrounding area in case there are any cells that can't be seen. Nearby lymph nodes may also be removed as these are often the first place a cancer will spread to.

If the whole tumour cannot be removed, surgery can also be used for 'debulking', where as much of the tumour is removed as possible so the rest can be treated with chemotherapy or radiotherapy. Surgery can also be palliative, relieving symptoms when cancer cannot be cured.

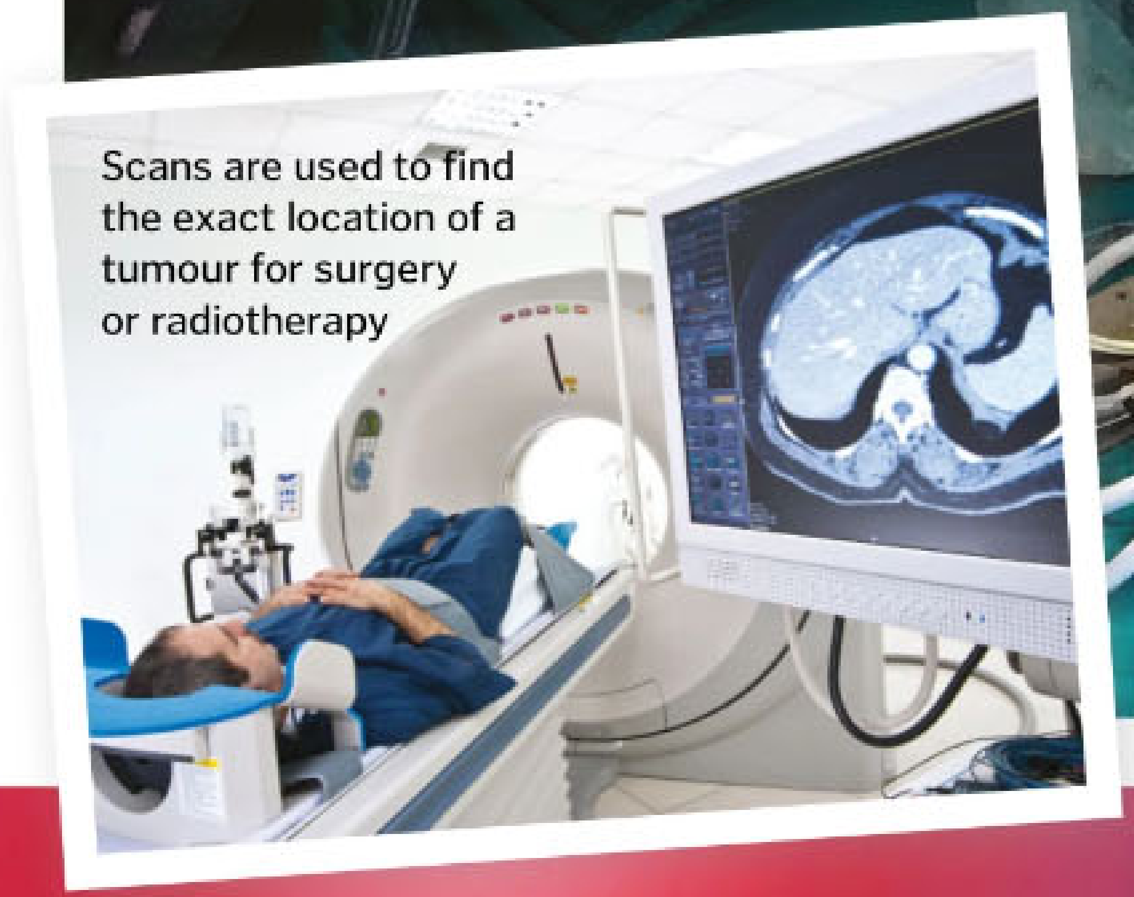
Not all lumps are tumours and not all tumours are cancer, so surgery is often used for cancer diagnosis, too. A small sample of tissue, known as a biopsy, is removed and either frozen solid or embedded in wax so that it can be thinly sliced. These slices are stained so that a pathologist can examine the structure of the cells and tissue.

Cancer cells look different under a microscope, creating disorganised structures in normally orderly tissues, and they also display specific molecular or genetic markers that single them out. These not only help with a cancer diagnosis but can also be used to determine the type of cancer, how advanced it is and the best form of treatment to use against it.





Robotic surgery allows precision operations to be performed



Scans are used to find the exact location of a tumour for surgery or radiotherapy

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The future of cancer treatment

The more we learn about cancer, the better we are able to target its weaknesses

In the UK, overall cancer survival is now at 50 per cent, and ten-year survival for testicular cancer has reached an impressive 98 per cent. But there's still a way to go. There are hundreds of different types of cancer, and even patients with the same cancer type have subtle differences in their tumours that change their response to treatment. Cancers can become resistant to chemotherapy and radiotherapy, and many treatments also harm healthy cells, causing side-effects that limit their use.

Until recently, most cancer treatments have focused on one thing: cell division. Both radiotherapy and chemotherapy hit rapidly dividing cells, damaging their DNA as they try to replicate, causing them to die. But cancer has lots of other weaknesses and scientists are attacking from all angles, using the latest tech to reveal their genetic and molecular differences.

One tactic is to cut cancer's fuel lines. As tumours grow and cells pile on top of one another, oxygen levels drop and the cancer cells encourage new blood vessel cells to break down tissue and migrate in. Blocking this process could stop tumour growth in its tracks.

Another option is to use the immune system, helping our own cells to see cancer cells and destroy them. Techniques being trialled include using molecules to block the interaction between cancer cells and immune cells, preventing the tumour from switching the immune system off, and genetically engineering immune cells to supercharge their ability to seek and destroy cancer cells.

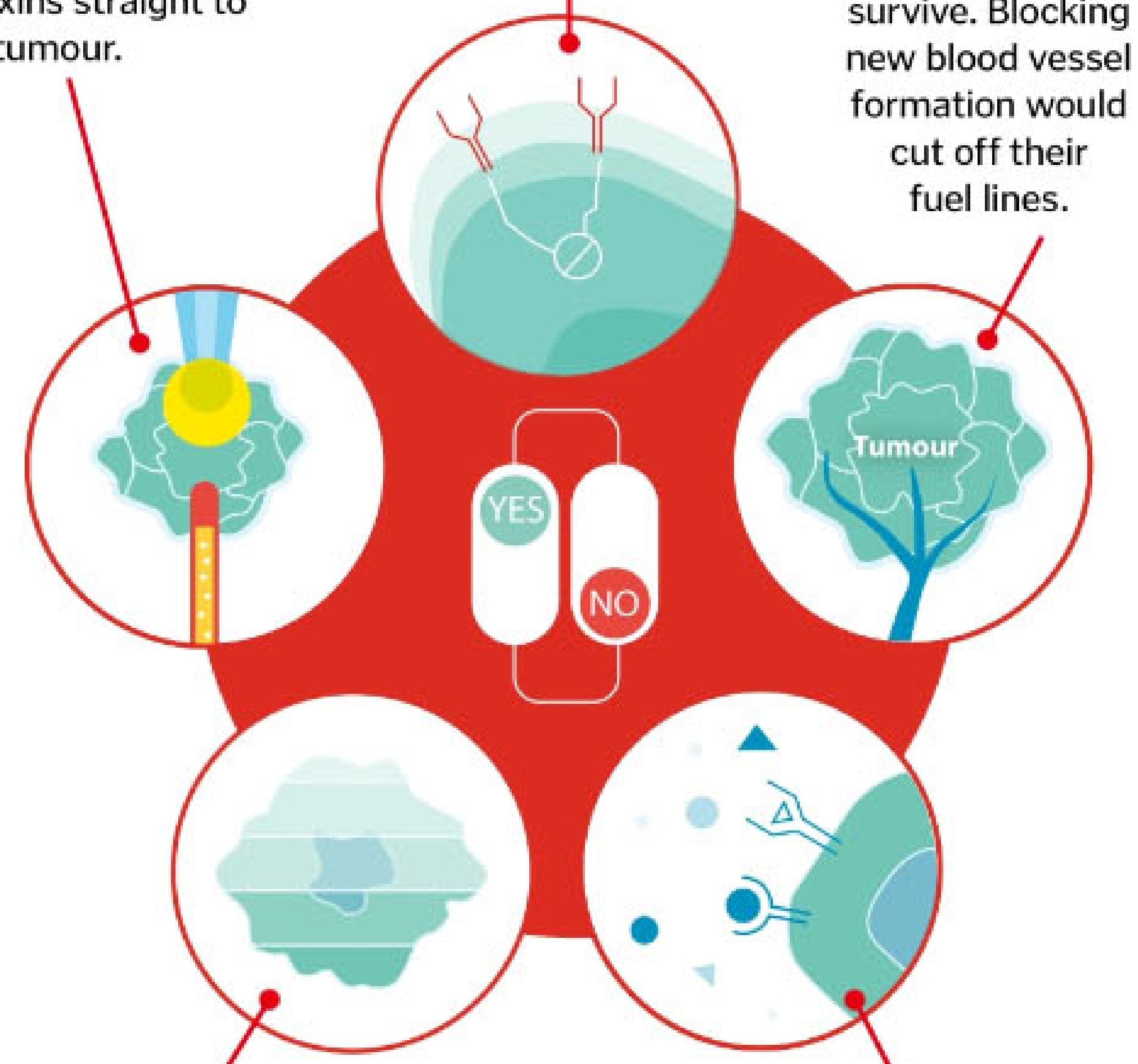
Immune molecules called antibodies are also being transformed into highly targeted cancer treatments that should leave healthy cells unharmed. They can be made to stick specifically to a single molecule, blocking the chemical signals that tumours need to survive or attaching directly to the cancer cells. They can even be linked to chemotherapy or radiotherapy molecules, delivering a double hit of toxin and immune attack.

Researchers are also working on genetically modifying viruses to infect and kill cancer cells, delivering drugs into cancer cells using nanoparticles and designing small molecules to interfere with the crucial molecular machinery that cancer cells use to survive.

It's very unlikely that there will ever be a single cancer cure, but the more we learn, the more targeted treatments will become, killing cancer cells more effectively and leaving healthy cells unharmed.

Targeting cancer's weaknesses

Modern techniques are zeroing in on the molecules and genetics that make cancer cells vulnerable



Molecular tags

Cancer cell molecules look different. Targeting these could deliver toxins straight to a tumour.

Growth signals

Cancer cells receive signals that tell them to keep growing. Blocking these could halt the process.

Blood supply

Cancer cells need a blood supply to survive. Blocking new blood vessel formation would cut off their fuel lines.

Self-destruction

Cancer cells don't die even though they are faulty. Targeted therapies could switch self-destruct systems on.

Hormones

Some cancer cells are driven by hormones. Stopping their production could slow growth.

Trawling cancer genetics

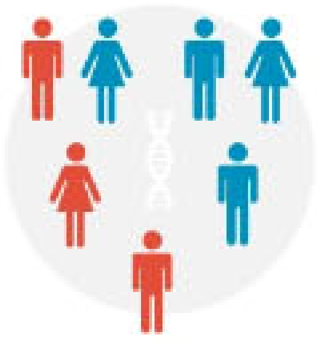
Cancers have distinctive mistakes in their genetic code that could reveal weaknesses.

Pathology

Cancer cells can be tested for the presence of molecules that single them out as defective.

Custom treatment

Individual patients could be matched to the treatments most likely to work for their unique tumour.



Customising cancer treatment

The Human Genome Project unravelled the human genetic code in 2003. This epic sequencing mission detailed every single letter of our DNA, revealing for the first time the complete recipe book for a human body. Cancer cells read from the same recipe book as healthy cells, just with words blotted out, pages stuck together and sentences scrambled. By understanding how the recipe book is supposed to be put together, scientists are now better able to identify why and how cancer cells have got it so badly wrong.

Every person is slightly different and their cancer cells start with a slightly different set of instructions, and as the disease progresses, different tumours adapt in different ways. Two women might both have breast cancer, but although there are patterns of similarity, the genetics inside their cancer cells won't be exactly the same, so they don't always respond in the same way to treatment. In the future, people will be tested to reveal the targeted treatments that will work best for them.

Different cancers carry different mistakes and respond differently to treatment

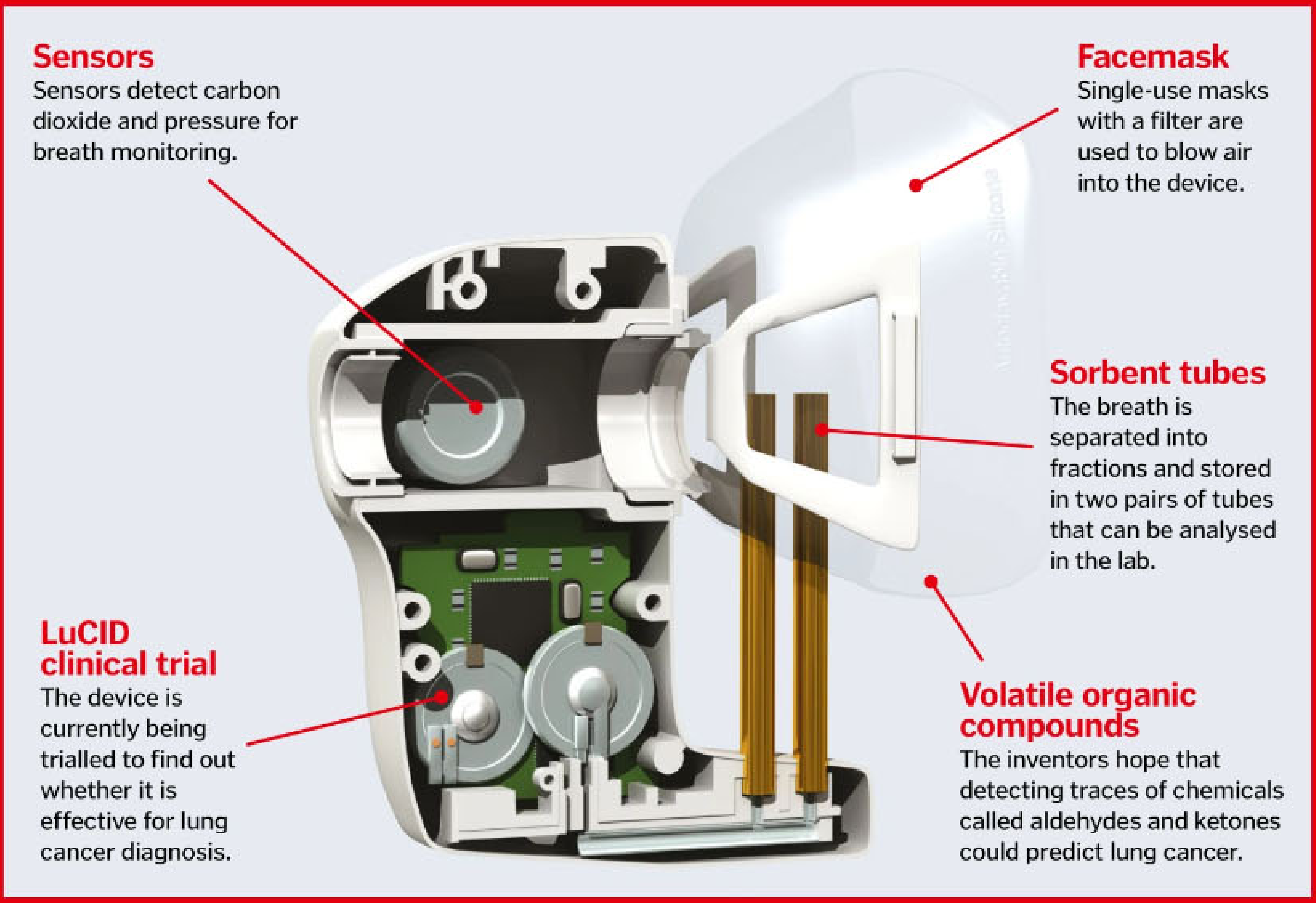
DID YOU KNOW? *Every new treatment has to pass through three phases of clinical trial testing before it can be licensed for use*

Catching cancer early

The sooner cancer is detected, the easier it is to treat. There are already three screening programmes in operation in the UK to detect bowel cancer, breast cancer and cervical cancer, but in the future things could become a whole lot simpler. Research into 'biomarkers' is searching for molecular signals that could reveal cancer in a simple blood, urine or even breath test.

Biomarkers are molecular signatures unique to different types of cells. Cancer cells differ from normal cells in ways that can already be detected using biopsies of tumour tissue, but researchers think that these differences might also make their way into body fluids, allowing them to be picked up with a simple test. Biomarkers might be able to reveal clues about the best treatment to use, whether the tumour is becoming resistant to current drugs and whether cancer has returned.

> "One tactic is to cut cancer's fuel lines"



Sensors
Sensors detect carbon dioxide and pressure for breath monitoring.

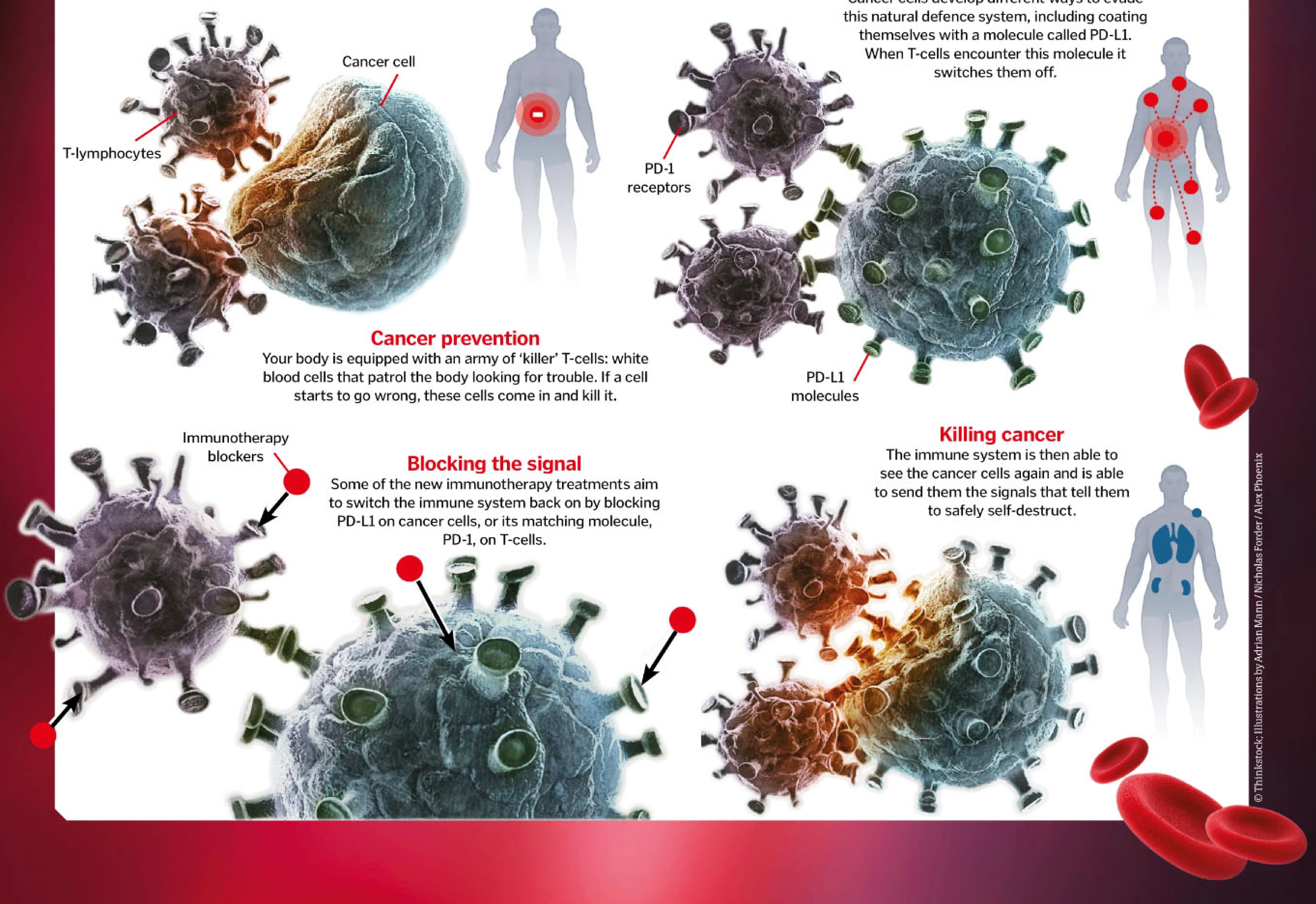
Facemask
Single-use masks with a filter are used to blow air into the device.

Sorbent tubes
The breath is separated into fractions and stored in two pairs of tubes that can be analysed in the lab.

LuCID clinical trial
The device is currently being trialled to find out whether it is effective for lung cancer diagnosis.

Volatile organic compounds
The inventors hope that detecting traces of chemicals called aldehydes and ketones could predict lung cancer.

Strengthening your immune army



Cancer prevention
Your body is equipped with an army of 'killer' T-cells: white blood cells that patrol the body looking for trouble. If a cell starts to go wrong, these cells come in and kill it.

Subterfuge
Cancer cells develop different ways to evade this natural defence system, including coating themselves with a molecule called PD-L1. When T-cells encounter this molecule it switches them off.

Blocking the signal
Some of the new immunotherapy treatments aim to switch the immune system back on by blocking PD-L1 on cancer cells, or its matching molecule, PD-1, on T-cells.

Killing cancer
The immune system is then able to see the cancer cells again and is able to send them the signals that tell them to safely self-destruct.

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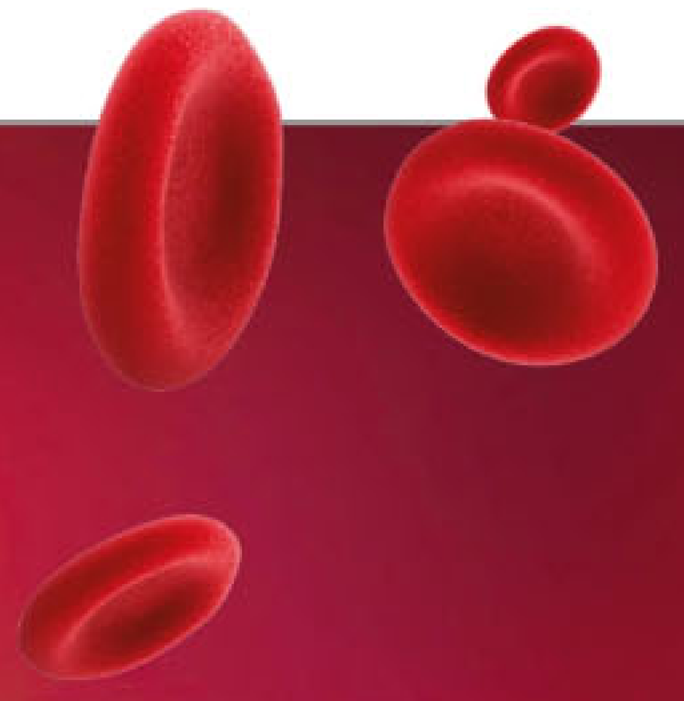


Expert opinion

How It Works spoke to an immunologist and a research nurse about the future of cancer treatment

The immunologist

***Dr Edd James** is an associate professor in cancer immunology at the University of Southampton, one of the country's leading centres for immunotherapy research*

Could you tell us a bit about your research? What are you trying to find out?
The immune system, in particular the 'infantry' known as killer T-cells, are able to detect cancer cells through examining small protein fragments presented on larger proteins called MHC at the surface of cells. Almost all cells have these MHC molecules and they act as a way to understand what is going on in the cell at that moment. Despite these molecules, cancer cells are able to 'hide in plain sight' from the killer T-cells. We are investigating how they do this and how to either reverse this process or re-educate the killer T-cells to be able to 'see' the cancer cells through changing what the MHC molecules show them.

Why can't the immune system just kill cancer cells on its own?
In many instances, the immune system does kill cancer cells at an early stage of development without us knowing about it. However, cancer cells 'evolve' to hide themselves to prevent the immune system from finding and attacking them. In addition, the cancer cells are able to promote an environment that suppresses the immune response, thus preventing it from working properly.

How does immunotherapy help?
Immunotherapy works in many ways, but there are two main methods by which it can help. The first is to target molecules that the cancer cells have on the cell surface using proteins called antibodies. These are specific for particular molecules and once bound to the target molecules serve to highlight the targeted cancer cells to the immune system. This allows them to be identified, attacked and destroyed.

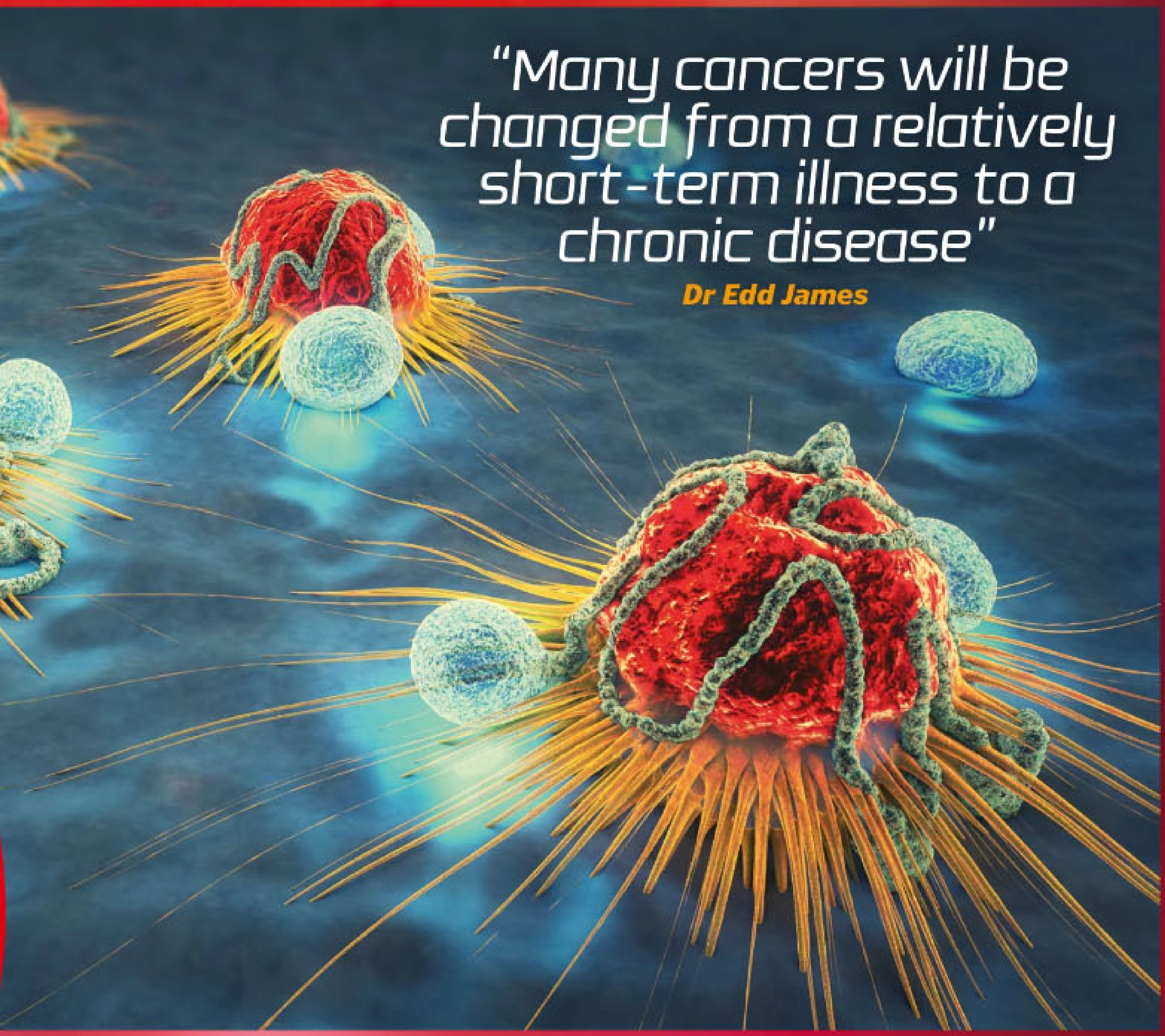
The second method is to target the killer T-cells themselves. Cancer cells are able to put the brakes on the killer T-cells to prevent them working properly. This occurs because the cancer cells deliver a negative, inhibitory signal to the killer T-cells through interaction. These signals are produced through a number of different molecules that can be blocked using antibodies. Blocking these interactions prevents the negative signals and allows the killer T-cells to work normally and kill the cancer cells.

What needs to be done next to make immunotherapy better?
Currently the therapies that are used are relatively blunt tools and aren't effective in many people. We need to understand how the cancer blocks the immune system in greater detail. This will give us a better appreciation of the processes involved in allowing cancer cells to evade the immune system and also allow us to identify new molecules to target.

There are many new investigations looking to combine current immunotherapies to improve their success. In trials these are working much better. However, a major downside of many of these combinations is an increase in side- effects that needs to be addressed.

Do you think we will ever cure cancer?
There is likely to be an effective cure for a number of cancers in the future. Our greater understanding of the molecular aspects of a cancer, and how to utilise the immune system more effectively to kill the cancer, will greatly increase possible treatments and improve their efficacy. This will allow a much more personalised approach to treatment based on the molecular characteristics of the cancer.

These advances will mean that many cancers will be changed from a relatively short-term illness to a chronic disease, where patients are treated as and when cancer arises. This will increase cancer-free survival, effectively enabling many people to live a normal lifespan.



Edd is trying to help killer T-cells to see cancer cells

> "Many cancers will be changed from a relatively short-term illness to a chronic disease"
> **Dr Edd James**

Cells show the immune system what's happening inside them using MHC molecules

DID YOU KNOW? *Phase 3 trials compare new drugs to current drugs to see if they're more effective or have fewer side-effects*

The research nurse

***Jac Samuel** is a CRUK senior research nurse. She leads a team of research nurses delivering clinical trials testing brand new cancer treatments for the first time*

Could you explain a bit about what research nursing is?

Research nursing is a really interesting career pathway, which most nurses when they qualify don't even consider. You think you're going to work on a ward, and you obviously go into nursing because you want to look after people and help them. Research nursing is interesting because you're working with new treatments that are not licensed.

It's a process of gathering data, which is then analysed to see whether or not this new treatment is comparably better than what we've currently got. It might be that it works better, or it might be that it doesn't work any better but it doesn't have such bad side-effects. Or maybe, instead of giving it via somebody's vein, they might be able to take it in the form of a tablet.

As a research nurse you're delivering those treatments to patients. We don't know how well it works, so we're conducting an investigation. What we're aiming for is really good quality data that can be analysed to prove how well something is working.

Why do treatments have to go through trials?

You can't just give something from a lab because you don't know how it works. Even if it's worked in an animal model, you don't know how it's going to work in a human. Everything has to be tested to make sure it's safe. Otherwise you could have some company saying, 'Hey, we think this really works and it's a cure, and we're going to charge you £50,000 for it' but there would be no evidence for that.

The whole point of research is that it's evidence-based. The laboratories will create the treatment, and they will test it in a cell line and in an animal model, but it's very different to how it might work in a human.

What changes have you seen in cancer treatment?

I've been nursing for a long time now, but even in the last five years actually it has really changed. Scientists have so much more understanding now of the intricacies of cells. Before, there used to be a blanket term for several different sorts of cancer. It's so much more nuanced now, and I think this is only the tip of the iceberg.

There have been certain drugs that have turned it around for patients. Five or ten years ago, you knew with their diagnosis that their prognosis was not great, and yet now you're seeing patients with exactly the same type of disease out of treatment and going strong.

Do you think that there will ever be a cure for cancer?

I think it's really difficult to say that there is going to be one single cure for cancer. The trouble is cancer is such an umbrella term. You've got so many different sorts of cells in your body, and cancer can affect different types of cells in different ways.

I think that as we've seen such a big change in survival rates in the last ten or 15 years, in the next ten or 15 years you're going to see big breakthroughs that are going to make huge differences. We still don't have a cure for cancer, but more people are surviving cancer and their quality of life is better with their treatment, and I think that will continue.

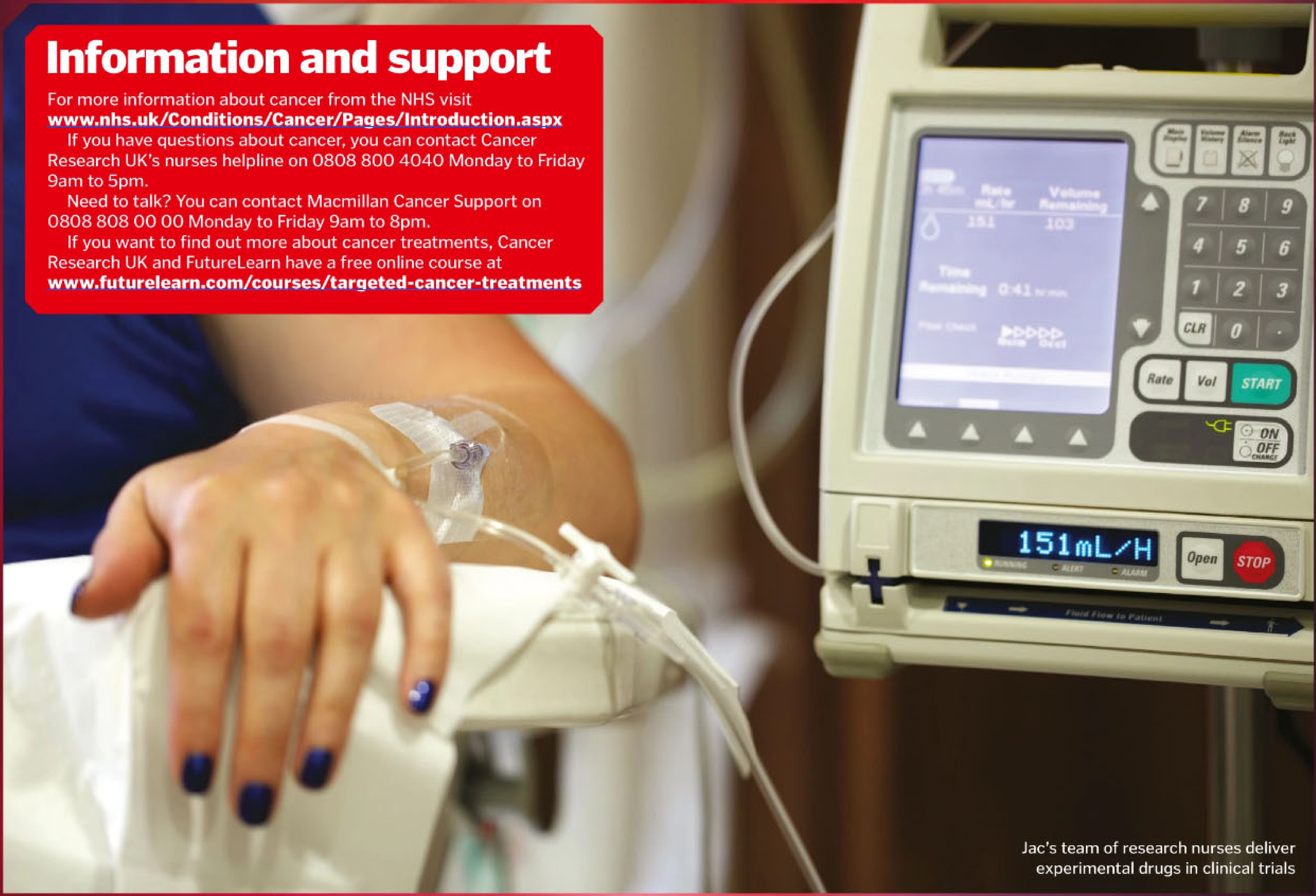
Information and support

For more information about cancer from the NHS visit **www.nhs.uk/Conditions/Cancer/Pages/Introduction.aspx**

If you have questions about cancer, you can contact Cancer Research UK's nurses helpline on 0808 800 4040 Monday to Friday 9am to 5pm.

Need to talk? You can contact Macmillan Cancer Support on 0808 808 00 00 Monday to Friday 9am to 8pm.

If you want to find out more about cancer treatments, Cancer Research UK and FutureLearn have a free online course at **www.futurelearn.com/courses/targeted-cancer-treatments**



Jac's team of research nurses deliver experimental drugs in clinical trials

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SPACE

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Farming on alien planets

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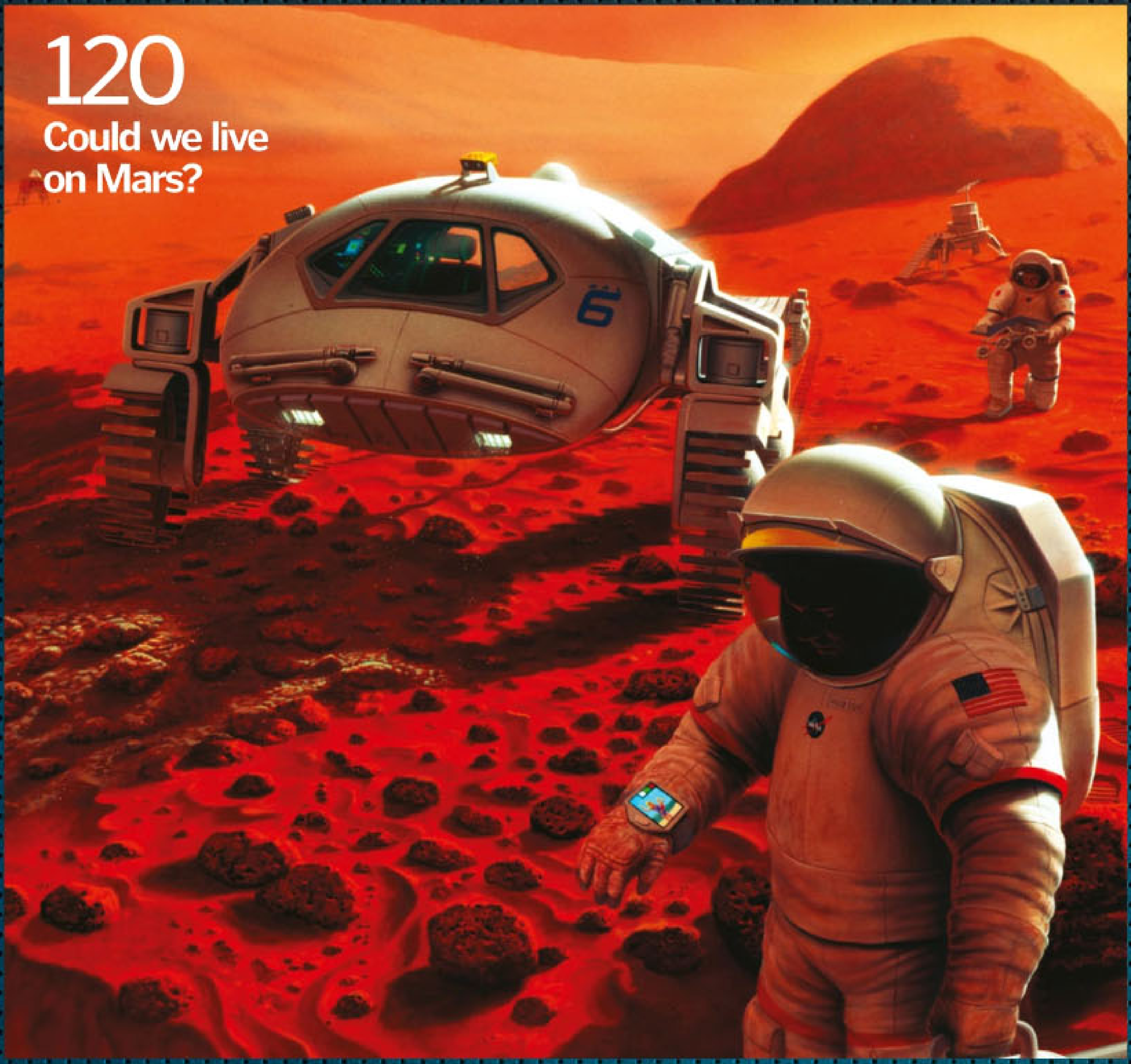
Spaceport America

138 Living on the moon



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Could we live on Mars?

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Could there ever be human populations on Mars?

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This mission will bring back a chunk of asteroid

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Rockets of the future

LIFE ON MARS

HOW WE'VE EXPLORED THE RED PLANET – AND WHAT'S COMING NEXT

A brief history of Mars

How this world turned from habitable to deadly

4.5 BILLION YEARS AGO

Formation

The planet Mars forms, along with the other rocky planets in the Solar System.

4.5 TO 4.1 BN YEARS AGO

Pre-Noachian

A little-known period of Martian history when the planet was likely pounded by asteroids.

4.1 TO 3.7 BN YEARS AGO

Noachian

Volcanic activity thickened the atmosphere, causing rain, forming valleys and lakes we see remnants of today.

DID YOU KNOW? *Mars may now be coming out of an ice age, as there is evidence that its polar ice caps are melting*

In September 2016, SpaceX founder Elon Musk announced a bold plan to colonise Mars with humans. It made headline news around the world, and while there are understandably some critics, it has once again raised the prospect of exploring Mars.

Today, Mars is a barren and inhospitable world. With an atmosphere that's 95 per cent carbon dioxide, temperatures as low as -153 degrees Celsius and no magnetic field, it's not exactly a habitable location. But several billion years ago, we're pretty sure Mars had vast amounts of water. We can see evidence for this in what appear to be valleys carved by rivers, empty lakebeds and even coastlines.

The big question remaining about Mars is whether life could have existed there, or still does. It is unclear how long the planet had surface water for, and it may not have been long enough for life to thrive. But it's possible that primitive, microbial life might have taken hold.

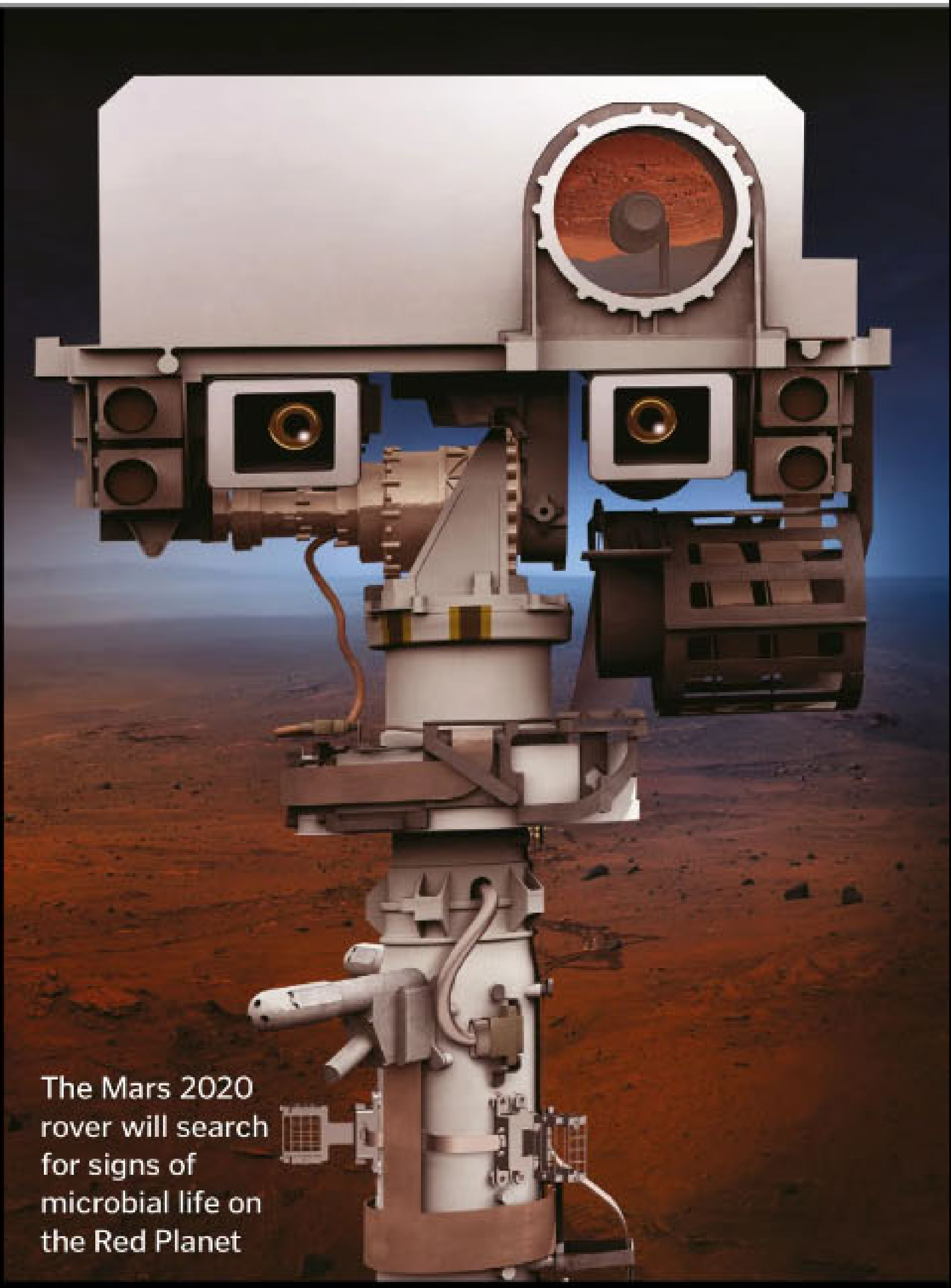
Two upcoming missions, the European ExoMars 2020 rover and the American Mars 2020 rover, will be endeavouring to answer this question. These two rovers are an exciting precursor to what looks set to be the era of Mars exploration.

At the moment, NASA is hard at work on a new spacecraft and rocket that will take people to Mars in the 2030s. Their goal is to further the exploration of the human species and, perhaps, create a permanent base on Mars.

Then Musk came along in September 2016 and threw a spanner in the works. He said he was working on a giant rocket that, beginning in the 2020s, would start launching people 100 at a time to Mars, with the goal of a million people settled there by the turn of the century.

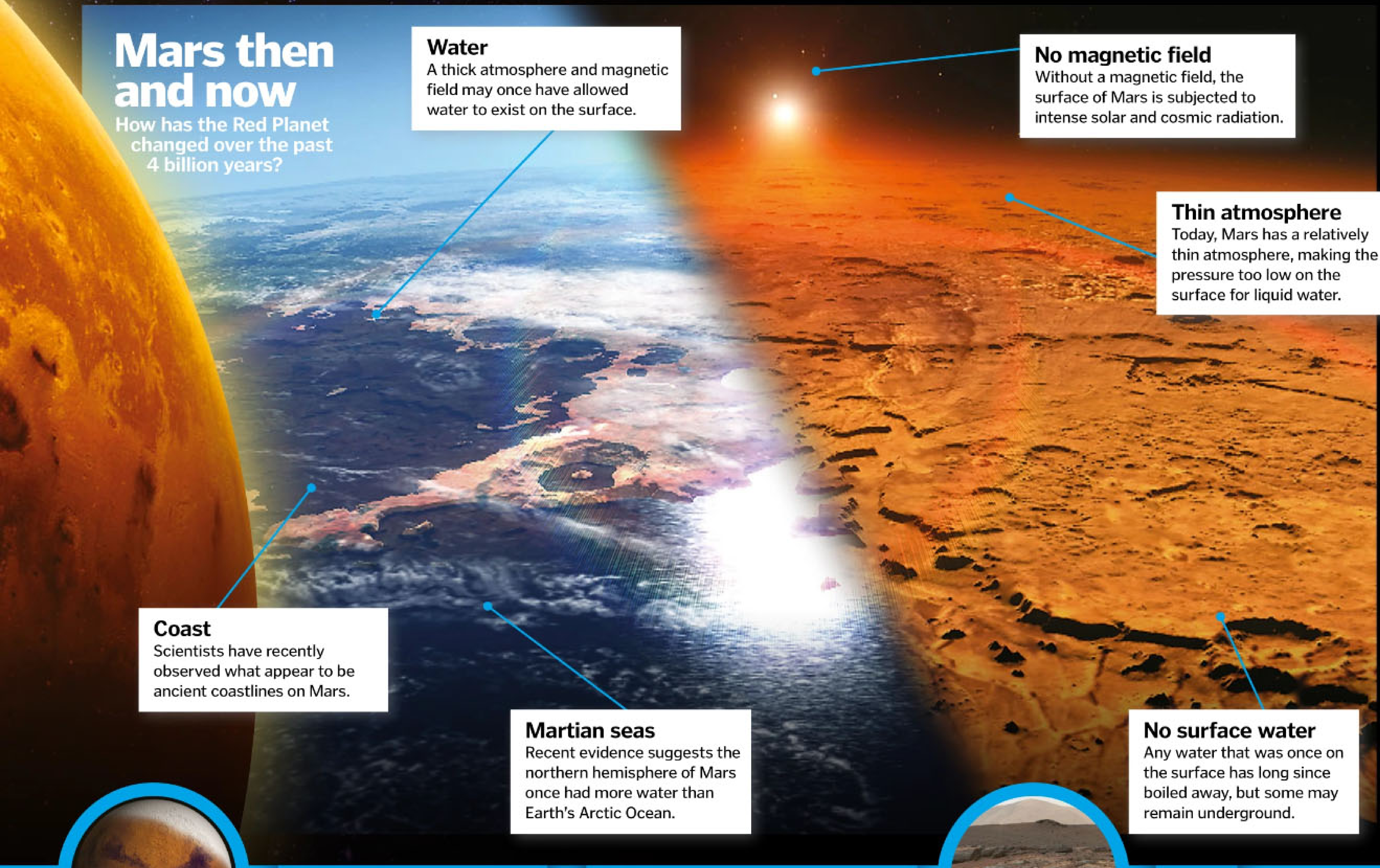
Mars is back on the agenda, and even if there has never been life there before, there soon will be: humans are homing in on the Red Planet.

> "We're pretty sure Mars once had vast amounts of water"


The Mars 2020 rover will search for signs of microbial life on the Red Planet

Mars then and now

How has the Red Planet changed over the past 4 billion years?



Water
A thick atmosphere and magnetic field may once have allowed water to exist on the surface.

No magnetic field
Without a magnetic field, the surface of Mars is subjected to intense solar and cosmic radiation.

Thin atmosphere
Today, Mars has a relatively thin atmosphere, making the pressure too low on the surface for liquid water.

Coast
Scientists have recently observed what appear to be ancient coastlines on Mars.

Martian seas
Recent evidence suggests the northern hemisphere of Mars once had more water than Earth's Arctic Ocean.

No surface water
Any water that was once on the surface has long since boiled away, but some may remain underground.

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3.7 TO 2.9 BN YEARS AGO
Hesperian
Much of Mars' surface water turned to ice as temperatures dropped during this period.

2.9 BN YEARS AGO TO PRESENT
Amazonian
Over the past few billion years, a thinning atmosphere left much of the planet smooth, dry and devoid of geologic activity.

TODAY
Present day
Mars is now a cold and barren world, with only hints of its ancient water remaining.

Robots on Mars

How we're using robotic explorers to uncover the Red Planet

In July 1965, NASA's Mariner 4 spacecraft conducted a flyby of the Red Planet, returning the first ever images of the Martian surface. Since then, we have learned a huge amount from our robotic missions – and perhaps it won't be too long until humans are there, too.

When we first started sending missions to Mars, scientists were unsure what they'd find. But over time, we have been able to paint a picture of what this world once looked like. The goals of our missions have changed too, from those of initial discovery, to more refined searches for life and water.

NASA's Viking landers arrived in 1976 and were the first dedicated probes to search for life. Results were inconclusive, but a fire was stoked in Martian exploration by returning the first images from the surface itself. However, following several failed attempts, it would be another two decades until the next successful Mars mission. NASA's Mars Global Surveyor launched in 1996, and between 1998 and 2006 it extensively mapped the surface and provided much of the data needed for later missions. Excitingly, it also provided evidence for water ice on Mars.

Our first rover arrived in 1997. Sojourner analysed rocks on Mars and found similar features to Earth. In 2004, the wildly successful Spirit and Opportunity rovers also arrived, with the latter still active on the surface today.

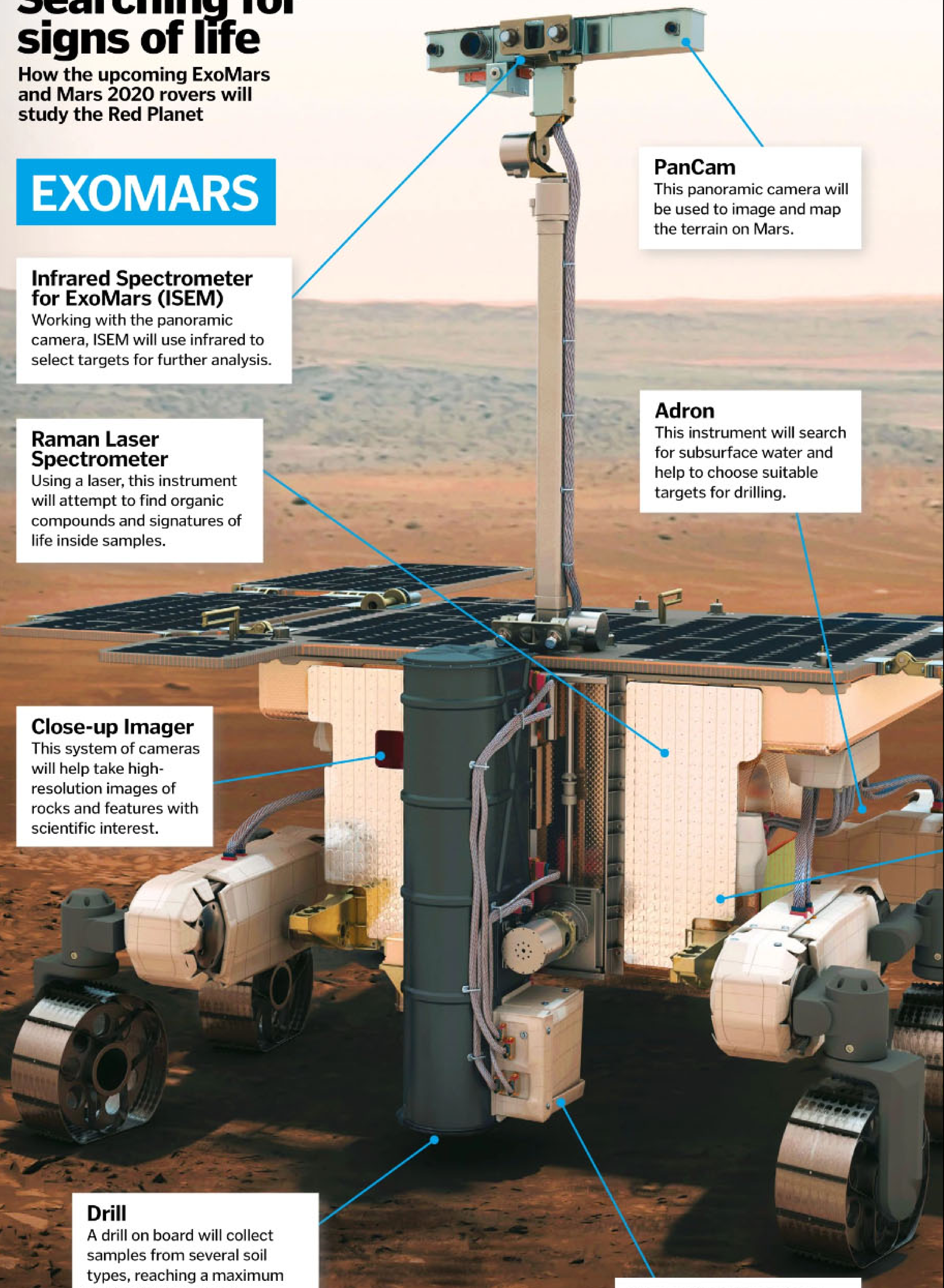
In 2012 we said hello to the Curiosity rover, which landed in Gale Crater, and has since discovered this location likely contained an ancient lake. 2014's MAVEN mission, meanwhile, has helped us discover how solar winds destroyed the Martian atmosphere.

But there's still much more to learn – and that's where ESA and NASA's amazing next generation of Martian rovers comes in.

Searching for signs of life

How the upcoming ExoMars and Mars 2020 rovers will study the Red Planet

EXOMARS



PanCam
This panoramic camera will be used to image and map the terrain on Mars.

Infrared Spectrometer for ExoMars (ISEM)
Working with the panoramic camera, ISEM will use infrared to select targets for further analysis.

Raman Laser Spectrometer
Using a laser, this instrument will attempt to find organic compounds and signatures of life inside samples.

Adron
This instrument will search for subsurface water and help to choose suitable targets for drilling.

Close-up Imager
This system of cameras will help take high-resolution images of rocks and features with scientific interest.

Drill
A drill on board will collect samples from several soil types, reaching a maximum depth of two metres.

Mars Multispectral Imager for Subsurface Studies
This instrument will help study the mineralogy of rocks encountered by the drill.

A history of water on Mars

How we've painted a picture of a once habitable world

CANYONS – 1971

Mariner 9
NASA's Mariner 9 spacecraft found a vast canyon on Mars and beamed back images of the planet's south pole.

RIVERS – 1976

Viking 1 and 2
The Viking landers found evidence that rivers of water had spread far across the surface.

SALTY – 1997

Pathfinder
Pathfinder found that temperatures on Mars were high enough to support salty liquid water.

DID YOU KNOW? *Data from Mars Odyssey suggested there was enough ice under the surface of Mars to fill Lake Michigan twice*

Methane on Mars

In 2014, NASA's Curiosity rover had discovered a temporary increase of methane in its location on Mars. This hinted at – but does not prove – the presence of biological processes.

An instrument on board the rover called Sample Analysis at Mars (SAM) 'sniffed' the atmosphere over the course of 20 months. In two of those months, there were spikes of methane that were ten times larger than the average in other months.

This suggests there was a localised methane source. There are several possible causes, including the interaction of rock and water underground. But there could be a biological reason, perhaps subsurface microbes releasing methane. It raises the possibility that some basic life may still exist on Mars today.

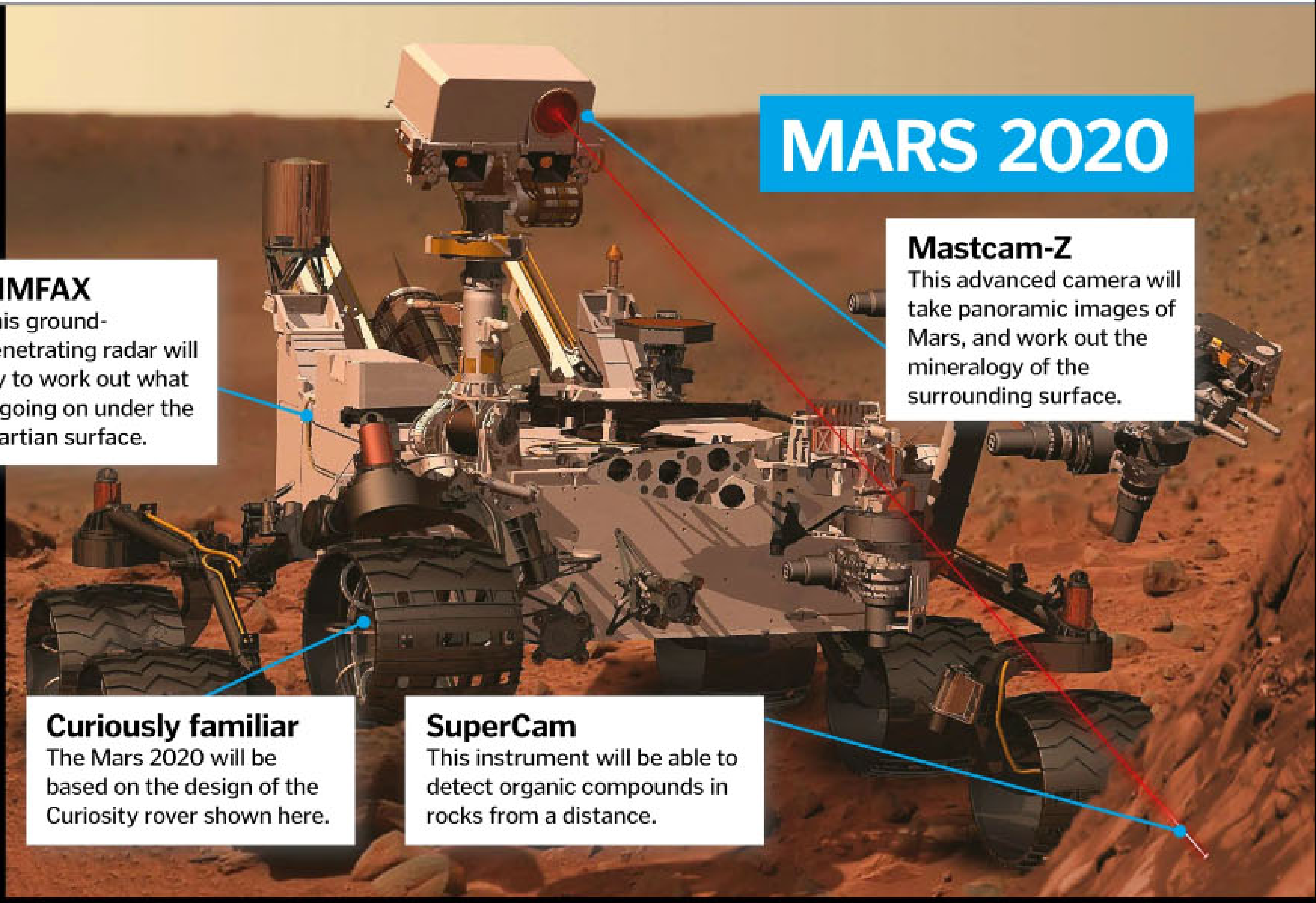
Curiosity found spikes in methane levels on Mars

Mars Organic Molecule Analyser
The biggest instrument on ExoMars, MOMA will directly try to find biomarkers in samples collected by the drill.

> "NASA's Viking landers were the first probes to search for life"

MAVEN is NASA's most recent spacecraft to be sent to Mars

MARS 2020

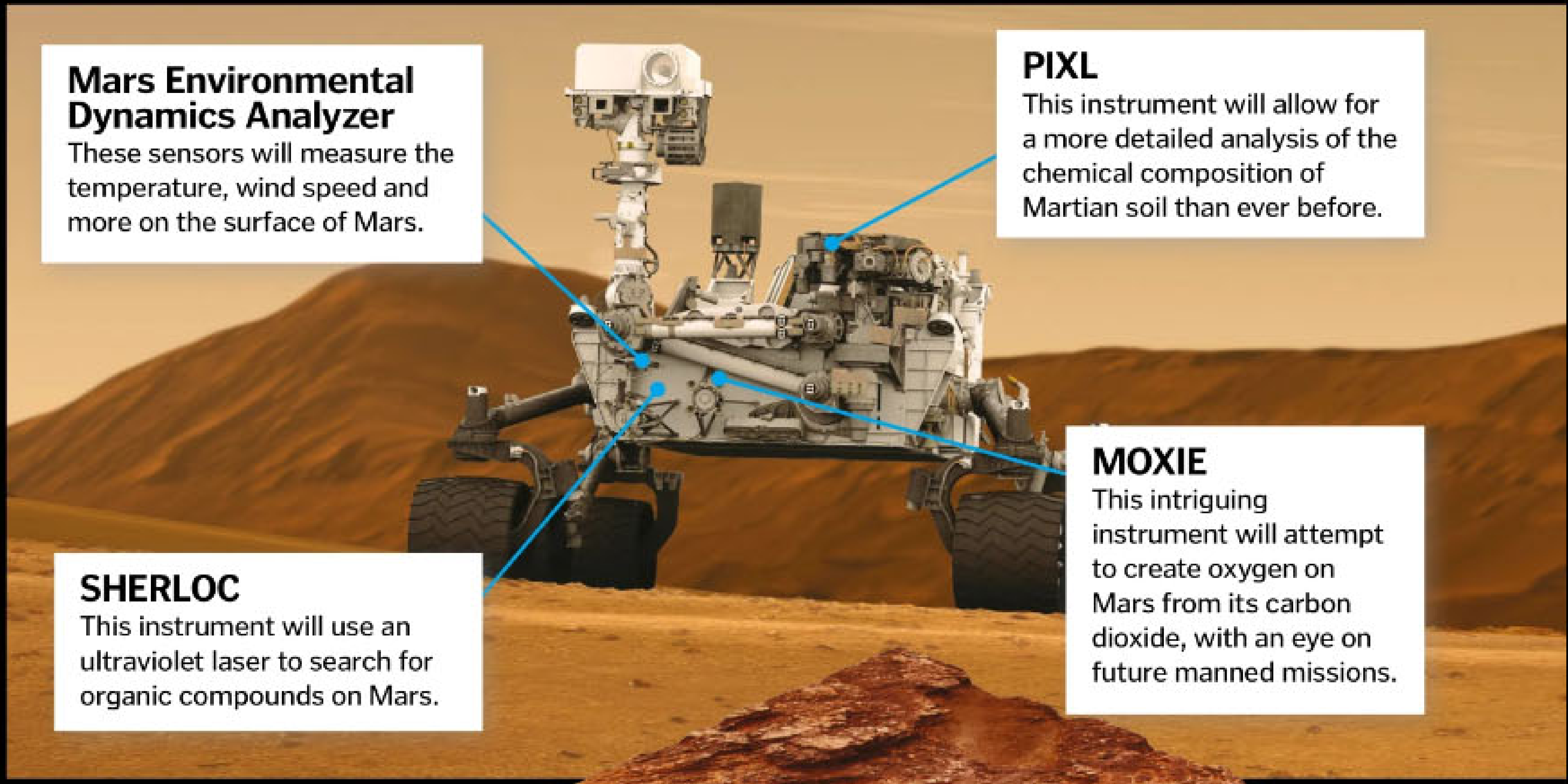


RIMFAX
This ground-penetrating radar will try to work out what is going on under the Martian surface.

Mastcam-Z
This advanced camera will take panoramic images of Mars, and work out the mineralogy of the surrounding surface.

Curiously familiar
The Mars 2020 will be based on the design of the Curiosity rover shown here.

SuperCam
This instrument will be able to detect organic compounds in rocks from a distance.



Mars Environmental Dynamics Analyzer
These sensors will measure the temperature, wind speed and more on the surface of Mars.

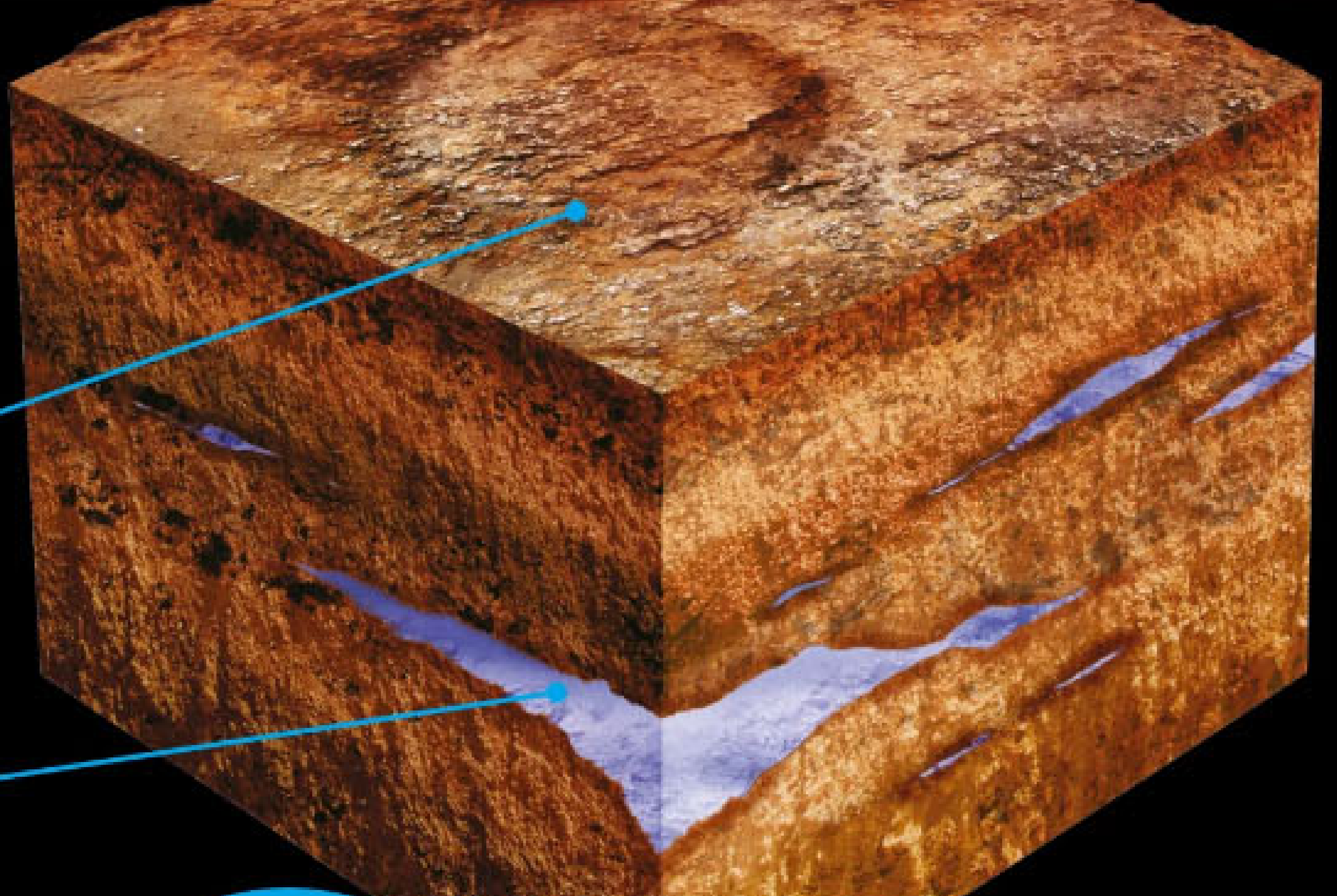
PIXL
This instrument will allow for a more detailed analysis of the chemical composition of Martian soil than ever before.

SHERLOC
This instrument will use an ultraviolet laser to search for organic compounds on Mars.

MOXIE
This intriguing instrument will attempt to create oxygen on Mars from its carbon dioxide, with an eye on future manned missions.

Hidden water

There could be ice or even liquid water trapped under the Martian surface



Clues
Geological features on the surface suggest Mars once had rivers, lakes and seas.

Reservoirs
Mars' surface is barren, but remnants of ice could be trapped underground.

© NASA/JPL; SPL

LIQUID – 1999

Mars Global Surveyor
Images from the Mars Global Surveyor between 1999 and 2001 suggested liquid water may still be flowing on Mars.

ICE – 2001

Mars Odyssey
This probe found that there could be huge deposits of ice and water below the surface of Mars.

STREAM – 2012

Curiosity
Curiosity has found that its landing site within the Gale Crater may have been an ancient stream bed.

Getting to Mars

How we're preparing for manned missions to the Red Planet

> "Elon Musk has revealed his bold plan to get to Mars"

The rockets

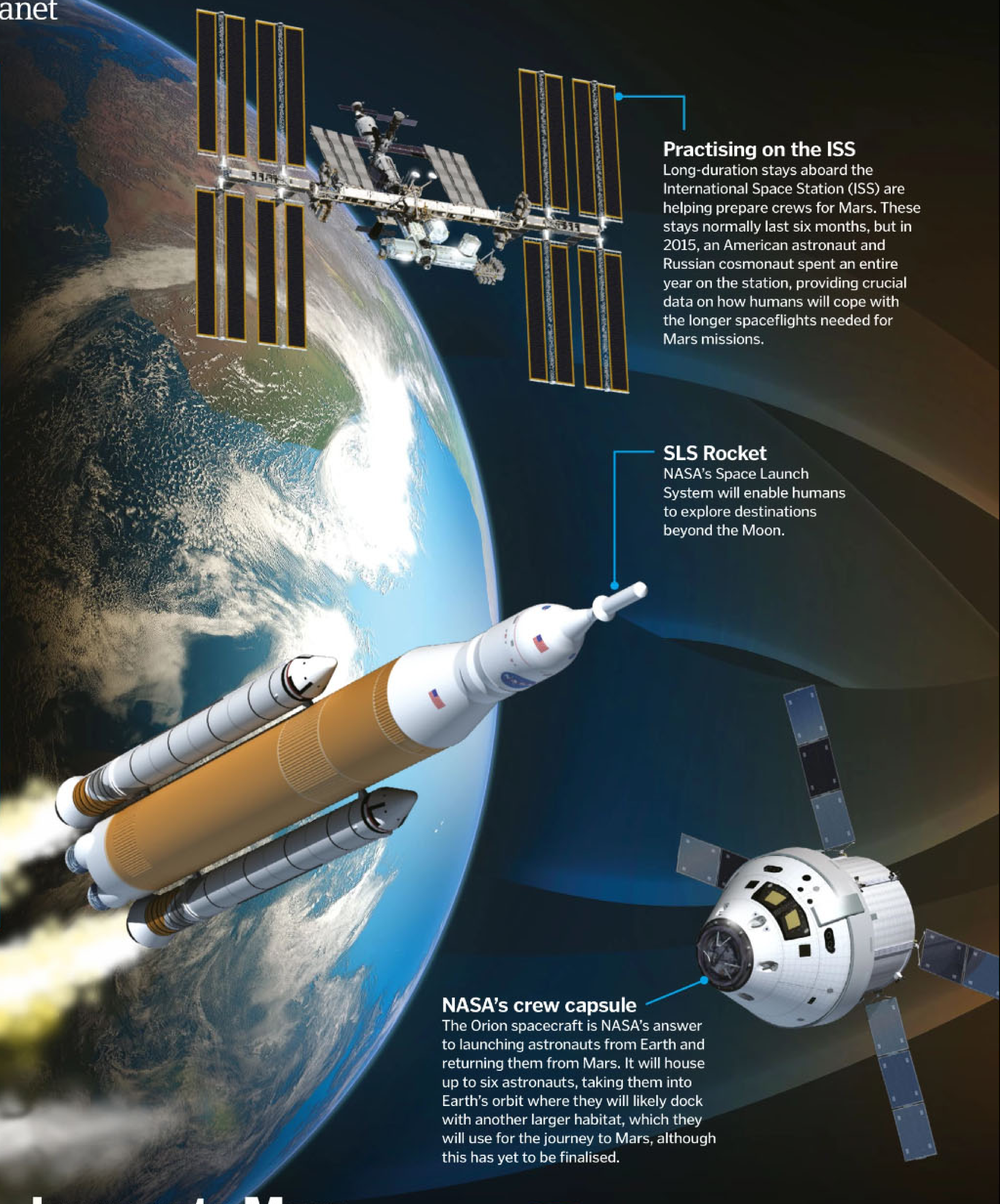
To get beyond Earth's orbit, you need a very big rocket. For the Apollo missions to the Moon, we had the Saturn V, which remains the most powerful rocket ever built. But for missions to Mars, things are going to need to get bigger – and better.

First up is NASA's Space Launch System (SLS). Measuring 117 metres in height, this heavy-lift rocket will launch astronauts and cargo to Mars. Its first test flight is not scheduled until 2018, though, and questions remain over how it will be used.

More recently, SpaceX founder Elon Musk revealed his bold plan to get to Mars with his Interplanetary Transport System (ITS). At a height of 122 metres, Musk wants to use this to colonise Mars with a million people by the turn of the century.

It is likely that Russia and China will also reveal rockets bound for Mars over the coming decades.

Will SpaceX's Interplanetary Transport System deliver on its promises?



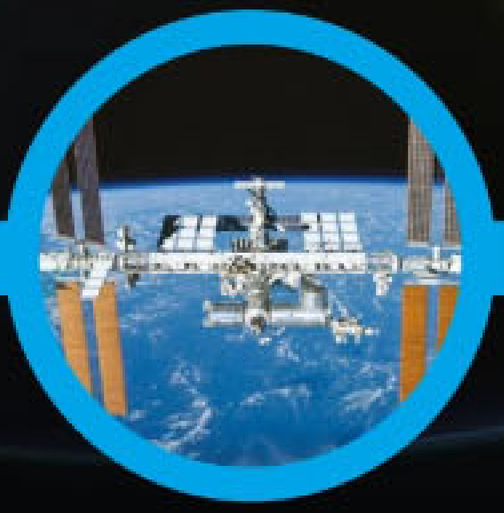
Practising on the ISS
Long-duration stays aboard the International Space Station (ISS) are helping prepare crews for Mars. These stays normally last six months, but in 2015, an American astronaut and Russian cosmonaut spent an entire year on the station, providing crucial data on how humans will cope with the longer spaceflights needed for Mars missions.

SLS Rocket
NASA's Space Launch System will enable humans to explore destinations beyond the Moon.

NASA's crew capsule
The Orion spacecraft is NASA's answer to launching astronauts from Earth and returning them from Mars. It will house up to six astronauts, taking them into Earth's orbit where they will likely dock with another larger habitat, which they will use for the journey to Mars, although this has yet to be finalised.

Journey to Mars

How NASA plans to send humans to Mars by 2040



PRESENT-2024

International Space Station
Missions to the ISS will continue until 2024, monitoring how humans cope with spaceflight.

2018

Exploration Mission-1
SLS and an unmanned Orion capsule will launch together for the first time in 2018.

2023

Asteroid Redirect Mission
By 2023, NASA plans to send humans to a captured asteroid in lunar orbit.

DID YOU KNOW? No humans have left Earth's orbit since December 1972, when Apollo 17 made the three-day journey to the Moon

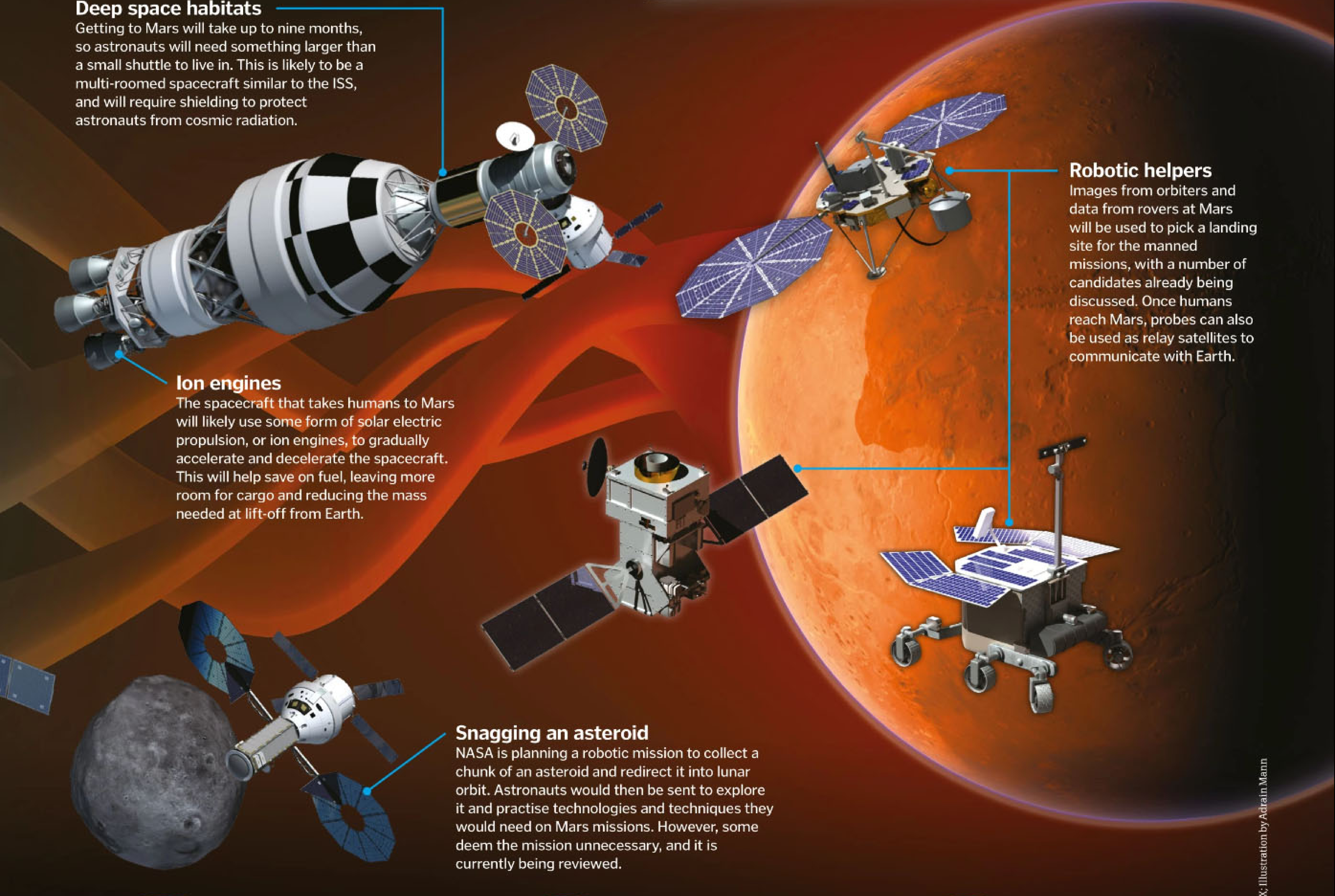
Simulating a Mars mission

On 28 August 2016, six people emerged from a two-story dome in Hawaii, having spent a whole year in isolation. Why? They were simulating what it might be like to live on Mars under similar conditions in the future.

The mission, called HI-SEAS (Hawaii Space Exploration Analog and Simulation), was part-run by NASA to prepare for its planned manned missions in the 2030s. During the experiment, the team spent their entire time inside the dome, having to don 'spacesuits' to venture outside, just as explorers will have to on future Mars missions. Their communications to Earth were also delayed by 20 minutes – the same lag Martian explorers will experience.

Although there's no substitute for actually being on Mars, the goal of this programme was to see how humans would cope with isolation. NASA's missions to Mars may last three years in total, including 500 days on the surface – a long time away from Earth and other human contact.

HI-SEAS uses a dome in Hawaii to simulate Mars missions



Deep space habitats
Getting to Mars will take up to nine months, so astronauts will need something larger than a small shuttle to live in. This is likely to be a multi-roomed spacecraft similar to the ISS, and will require shielding to protect astronauts from cosmic radiation.

Robotic helpers
Images from orbiters and data from rovers at Mars will be used to pick a landing site for the manned missions, with a number of candidates already being discussed. Once humans reach Mars, probes can also be used as relay satellites to communicate with Earth.

Ion engines
The spacecraft that takes humans to Mars will likely use some form of solar electric propulsion, or ion engines, to gradually accelerate and decelerate the spacecraft. This will help save on fuel, leaving more room for cargo and reducing the mass needed at lift-off from Earth.

Snagging an asteroid
NASA is planning a robotic mission to collect a chunk of an asteroid and redirect it into lunar orbit. Astronauts would then be sent to explore it and practise technologies and techniques they would need on Mars missions. However, some deem the mission unnecessary, and it is currently being reviewed.

© NASA; SpaceX; Illustration by Adrain Mann

2030
The Moon
By 2030, NASA wants to be conducting regular missions to lunar space.

2033
Phobos
NASA may launch a crewed mission to the Martian moon Phobos in around 2033.

2039
Mars
By the end of the 2030s, NASA plans to send humans to the surface of Mars.

Humans on Mars

What will we actually do when we get to the Red Planet?

Of all the aspects of sending people to Mars, what life will actually be like there is the most speculative of the lot. That's not to say people haven't thought about it, but no one yet knows for sure how humans will survive there.

What seems likely, though, is that the first missions to Mars will involve telerobotics. This will see humans orbit Mars, perhaps living on the Martian moon Phobos, and operate rovers on the surface. Without the communications delay that Earth-controlled rovers suffer, this could allow for much more rapid exploration of the surface.

Eventually, though, humans will set foot there. If Elon Musk is to be believed, these humans will be self-sustaining, living off the land and using clever equipment to create oxygen, water, and even make the planet Earth-like. It remains to be seen if his plan to have a million people living there by the turn of the century comes to fruition, though.

For NASA, the plans are likely to be simpler and more realistic. Think along the lines of the Apollo missions, with small crews venturing to the surface, staying on Mars for a few weeks or a few years, before returning home.

To create a habitat on Mars, it may be necessary to partially submerge a structure in the Martian soil. This will provide a barrier against cosmic and solar radiation, keeping the crews healthy.

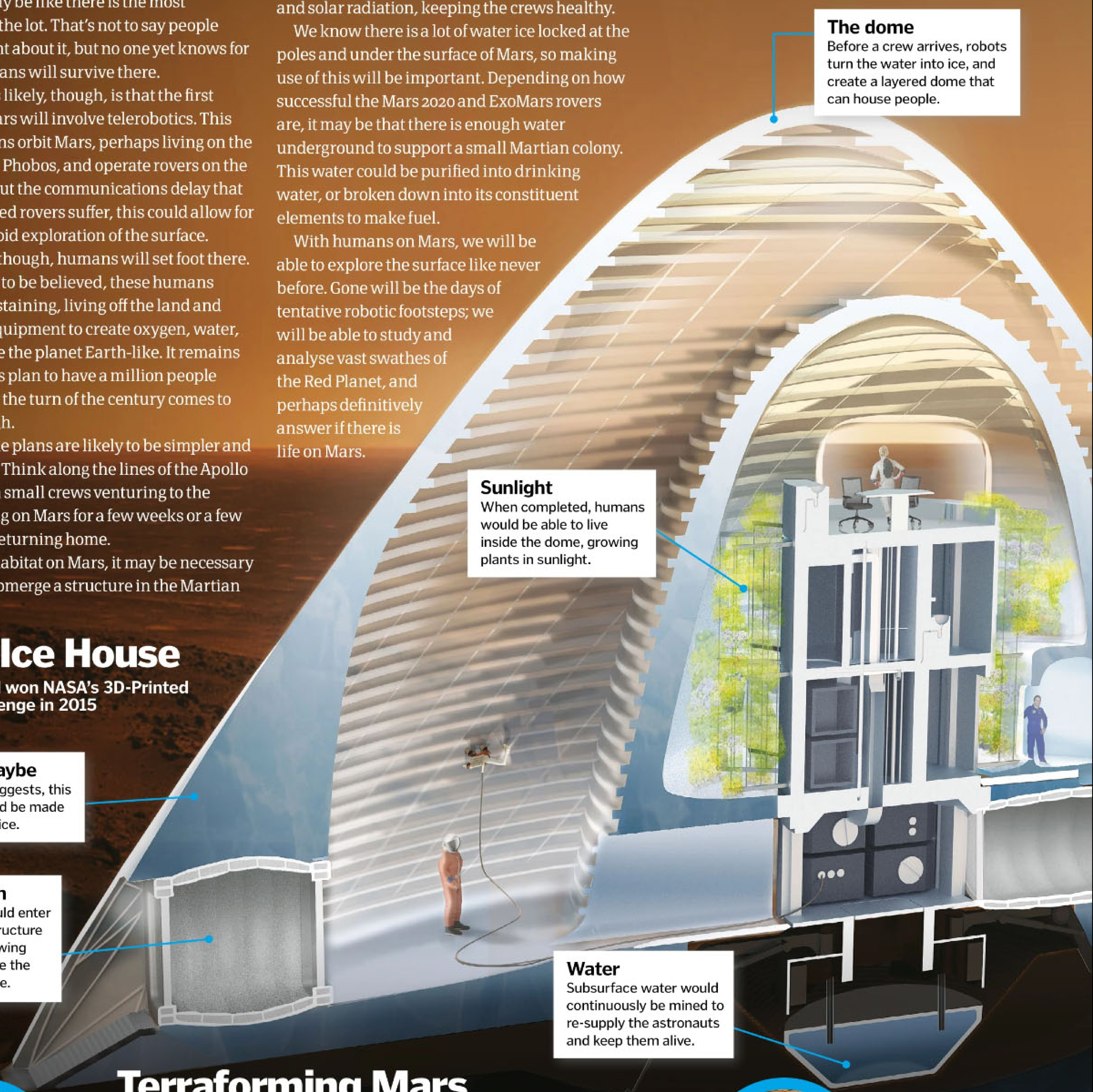
We know there is a lot of water ice locked at the poles and under the surface of Mars, so making use of this will be important. Depending on how successful the Mars 2020 and ExoMars rovers are, it may be that there is enough water underground to support a small Martian colony. This water could be purified into drinking water, or broken down into its constituent elements to make fuel.

With humans on Mars, we will be able to explore the surface like never before. Gone will be the days of tentative robotic footsteps; we will be able to study and analyse vast swathes of the Red Planet, and perhaps definitively answer if there is life on Mars.

> "People have long dreamed of turning Mars into an Earth-like world"

Mars Ice House

This proposal won NASA's 3D-Printed Habitat Challenge in 2015



The dome
Before a crew arrives, robots turn the water into ice, and create a layered dome that can house people.

Sunlight
When completed, humans would be able to live inside the dome, growing plants in sunlight.

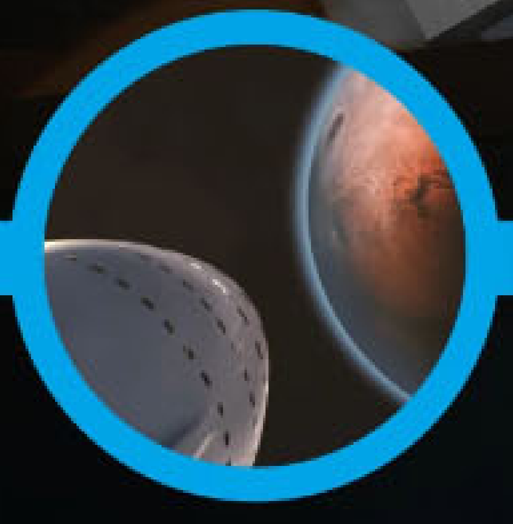
Ice, ice, maybe
As its name suggests, this structure would be made entirely out of ice.

Exploration
Astronauts could enter and exit the structure with ease, allowing them to explore the Martian surface.

Water
Subsurface water would continuously be mined to re-supply the astronauts and keep them alive.

Terraforming Mars

The steps we'd need to take to make Mars habitable



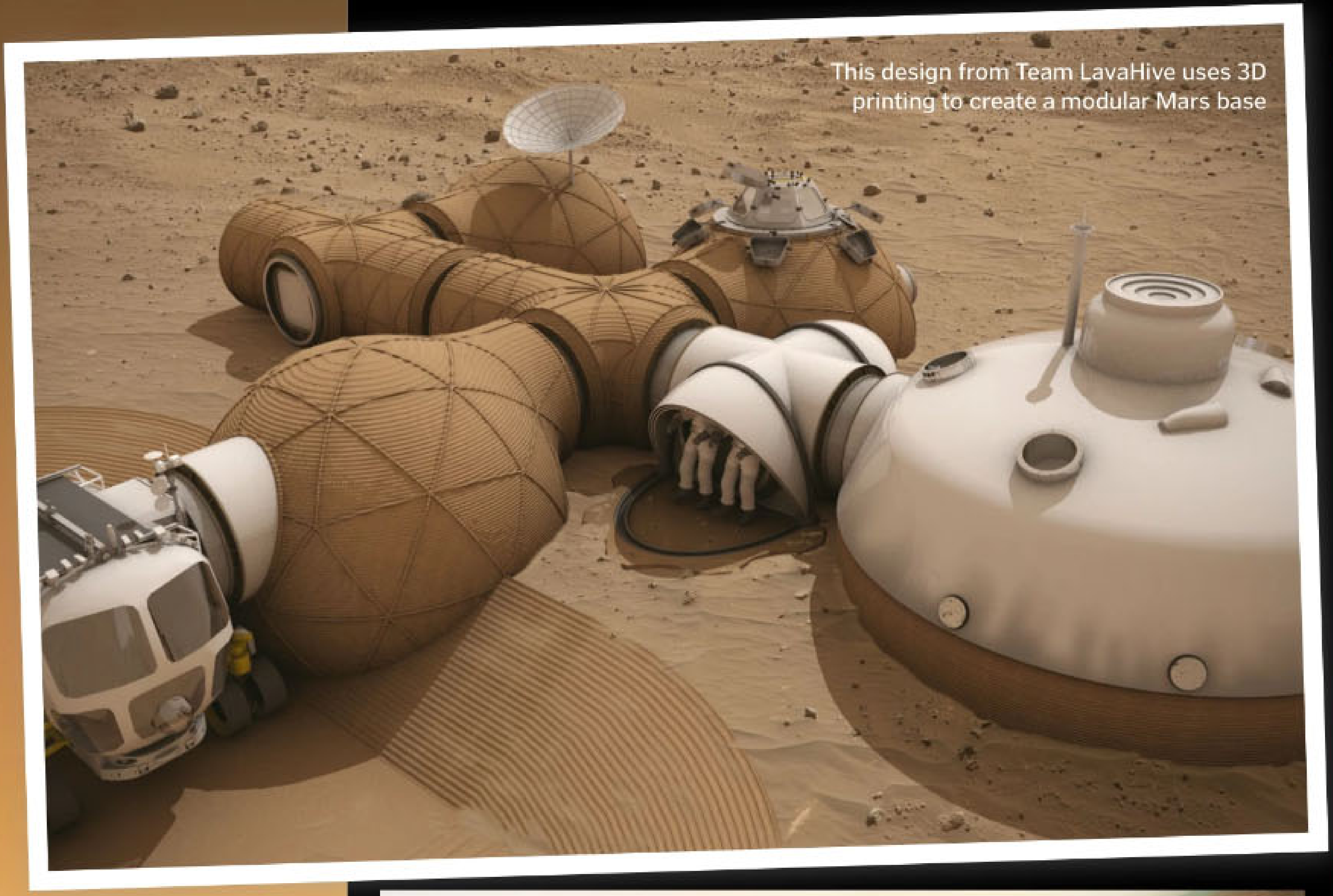
50 YEARS
Preparation
Send humans to Mars, and install the machinery necessary to terraform the planet.

100 YEARS
Colonisation
If Elon Musk is right, we could have a million people living on Mars in 100 years.

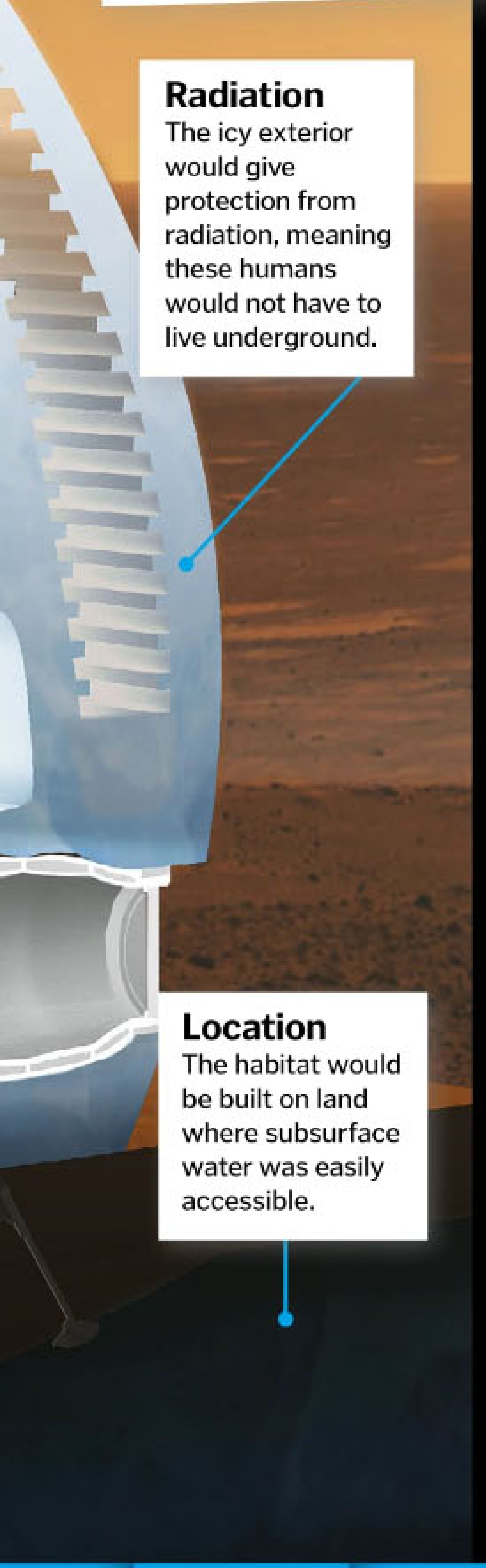
100 YEARS
Melting
By heating the poles we would release vapour and CO_2 into the atmosphere, heating the planet.

150 YEARS
Plants
By this point, oxygen levels may be suitable for plant life on the surface.

DID YOU KNOW? *Other places in the Solar System like Europa and Titan may once have played host to life, or perhaps still do*

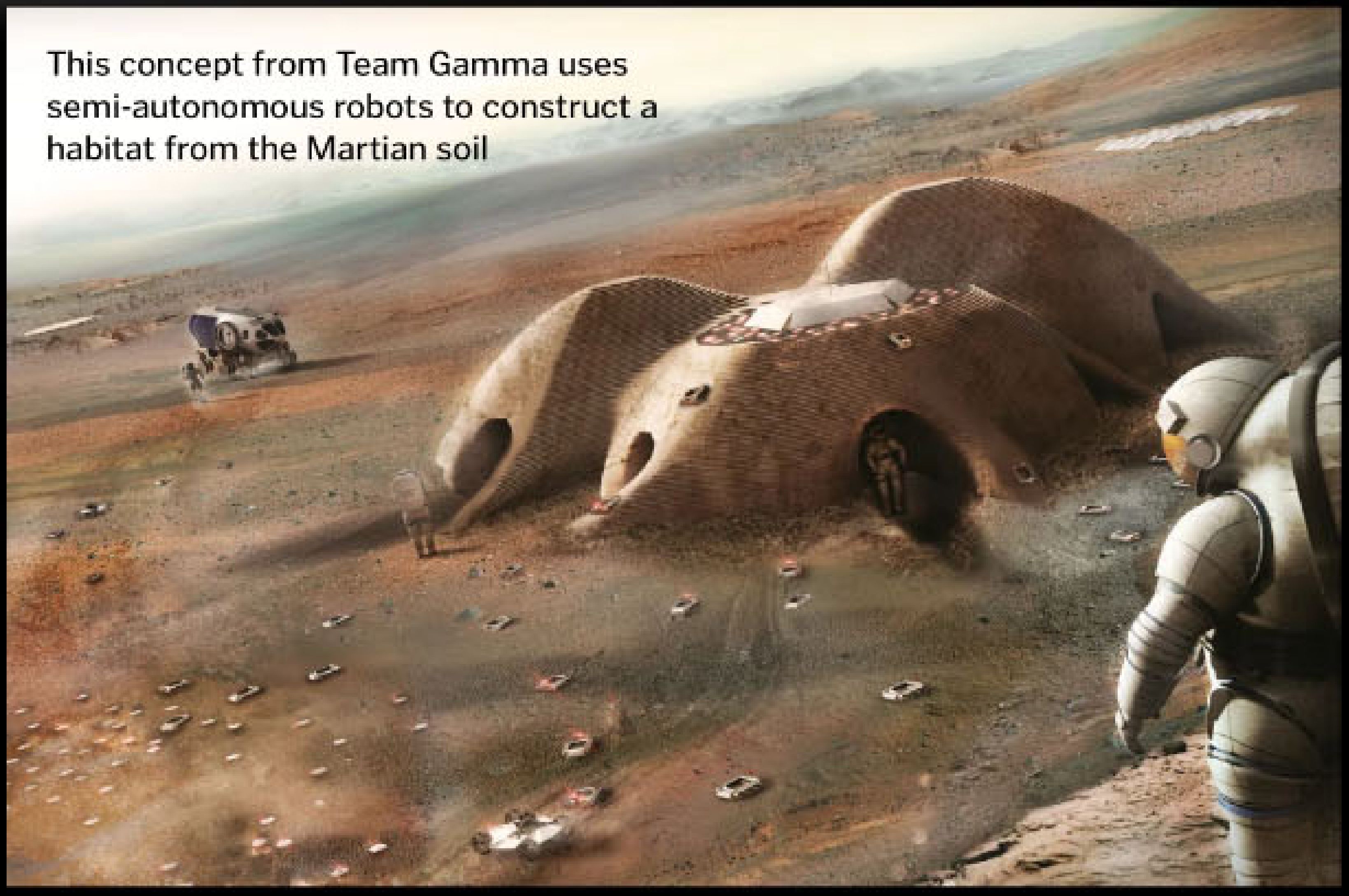


This design from Team LavaHive uses 3D printing to create a modular Mars base



Radiation
The icy exterior would give protection from radiation, meaning these humans would not have to live underground.

Location
The habitat would be built on land where subsurface water was easily accessible.



This concept from Team Gamma uses semi-autonomous robots to construct a habitat from the Martian soil

Habitat modules would have both private and communal spaces

900 YEARS

Humans
In an optimistic scenario, Mars could then be suitable for everyday human life in 900 years.

100,000 YEARS

The future
However, other estimates suggest it may take 10,000 to 100,000 years to terraform the planet. Stay tuned!

Can we make Mars habitable?

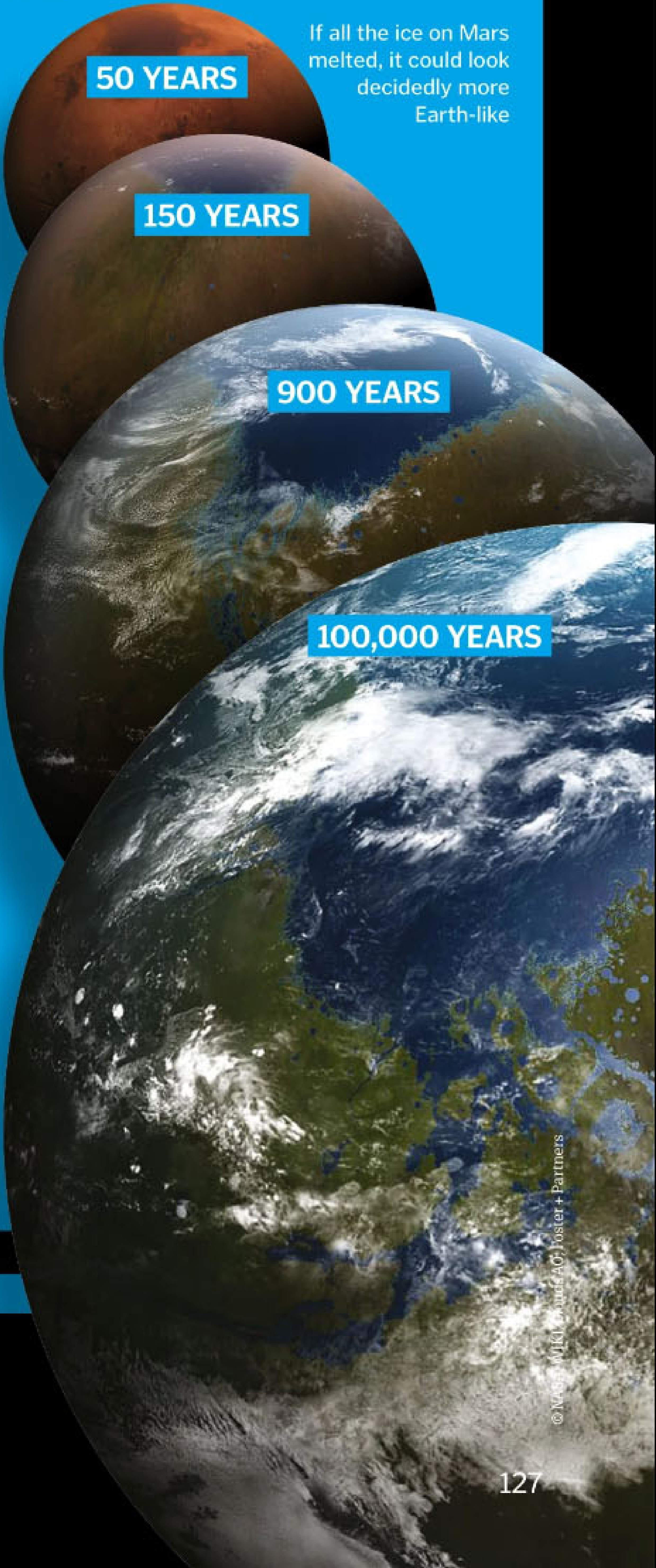
People have long dreamed of turning Mars into an Earth-like world. And it might be possible, although perhaps not just yet.

One way to do it would be to heat the vast amount of ice at the Martian poles, maybe with large mirrors in orbit. This would release carbon dioxide into the atmosphere, thickening it, and potentially heating up the planet.

Another method would be to use factories on the surface to manufacture chlorofluorocarbons (CFCs) from the air and soil. CFCs are responsible for Earth's ozone, which traps heat from the Sun, and perhaps we could create a similar effect on Mars.

We'd also need to find a way to turn the atmosphere from predominantly carbon dioxide into oxygen and nitrogen, like on Earth.

One complication, though, is that without a magnetic field, the Martian atmosphere is continuously blown away by the Sun. Who knows, though – perhaps there's a solution in the future.



If all the ice on Mars melted, it could look decidedly more Earth-like

© [illegible] Foster + Partners

OSIRIS-REx

How this mission will return a chunk of asteroid to Earth

Since the final Luna mission to the Moon in 1976, we have returned less than a gram of material from another celestial body to Earth. That's quite a shocking statistic if you think about it, but in 2023, it's all set to change.

NASA's OSIRIS-REx (Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer) will return the largest extraterrestrial sample to Earth since the Apollo missions, from an asteroid located beyond the orbit of Mars. Launched on 8 September 2016 from Cape Canaveral in Florida, OSIRIS-REx has begun its two-year journey to the asteroid Bennu, 7.2 billion kilometres from Earth.

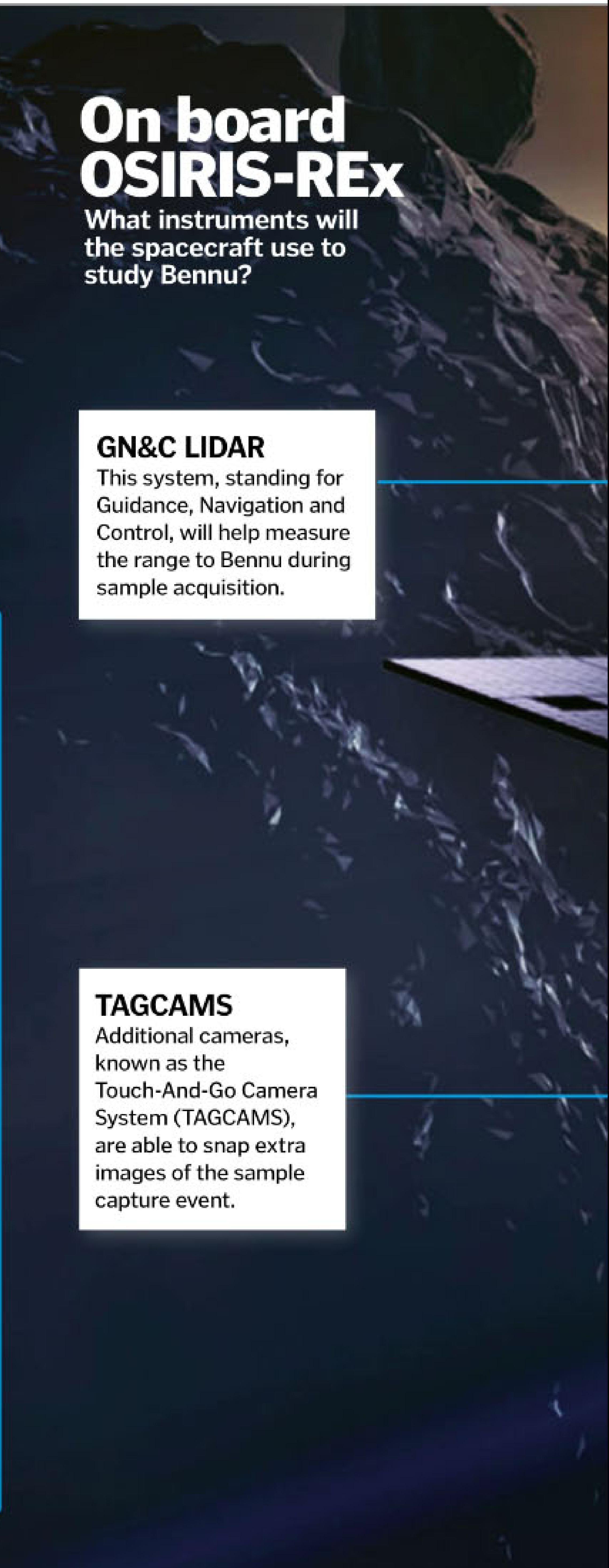
The craft, measuring 2.4 by 2.4 metres, will arrive at Bennu in August 2018. Less than two years later, it will use a robotic arm to grab a chunk of the asteroid, anywhere from 60 grams to two kilograms in size. It will then leave the asteroid in March 2021, and return the space rock sample to Earth in September 2023.

It's a highly ambitious mission, with a huge number of unknowns. For example, this is only the second mission to try to return a sample from an asteroid. The first, Japan's Hayabusa spacecraft, ran into a number of complications following its launch in 2003, including the process of actually collecting the sample, and only just managed to limp home with a tiny selection of rocky grains on board in 2010.

Scientists will be hoping for a better turn of events this time around, with the aim of furthering our understanding of asteroids – and also perhaps preventing a deadly impact with Earth in the future.

On board OSIRIS-REx

What instruments will the spacecraft use to study Bennu?



GN&C LIDAR

This system, standing for Guidance, Navigation and Control, will help measure the range to Bennu during sample acquisition.

TAGCAMS

Additional cameras, known as the Touch-And-Go Camera System (TAGCAMS), are able to snap extra images of the sample capture event.

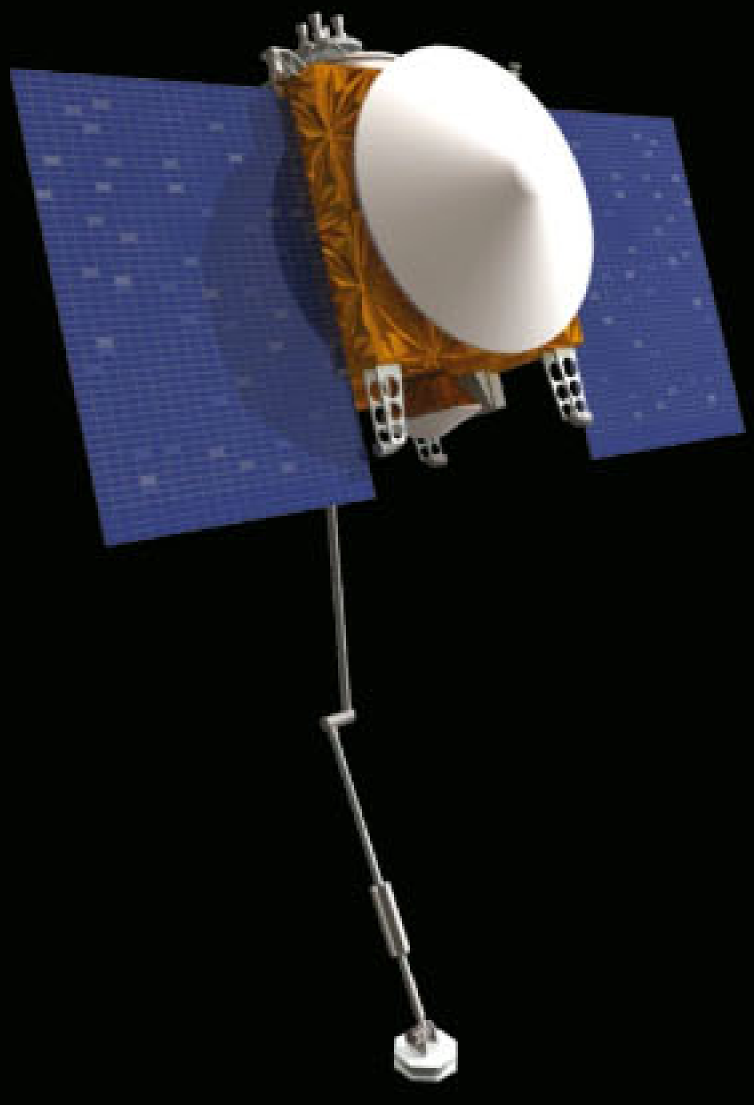
Mission goals

The main goal of the OSIRIS-REx mission is to return a sizeable sample to Earth for study, letting us see what asteroids like Bennu are made of, where they came from, and what role they had in the early Solar System. It's possible that asteroids like Bennu brought water to Earth, and possibly the ingredients for life, too.

Bennu also has a very small chance of hitting Earth in the late 22nd century, rated at one in 2,500. Scientists will study the effect of the Sun on the asteroid, known as the Yarkovsky effect, to see if this might push it more into our path in the future and raise the chance of it hitting us.

No one is quite sure what Bennu looks like yet

> "OSIRIS-REx will return the largest extraterrestrial sample to Earth since the Apollo missions"

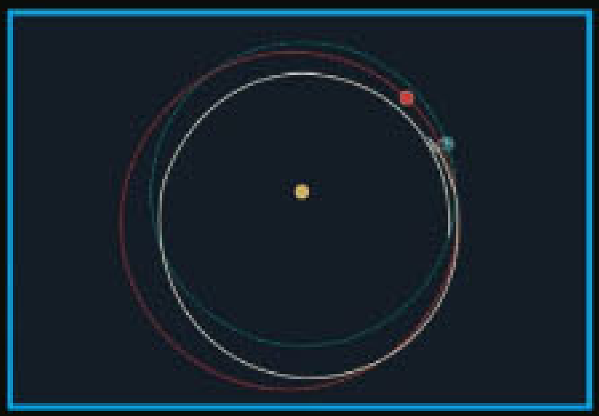


Mission timeline

How OSIRIS-REx will travel to Bennu and return to Earth

1. Launch
8 SEPTEMBER 2016

OSIRIS-REx successfully launched atop an Atlas V rocket from Cape Canaveral in Florida, and started its two-year journey to Bennu.

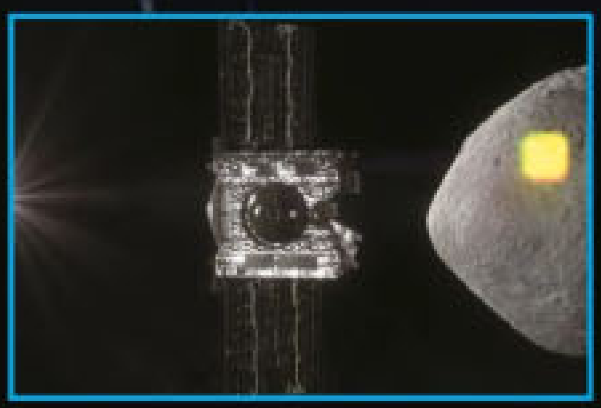


2. Gravity assist
23 SEPTEMBER 2017

OSIRIS-REx swung back past Earth after a year orbiting the Sun, giving it a boost from Earth's gravitational field towards Bennu.

3. Approach
AUGUST 2018

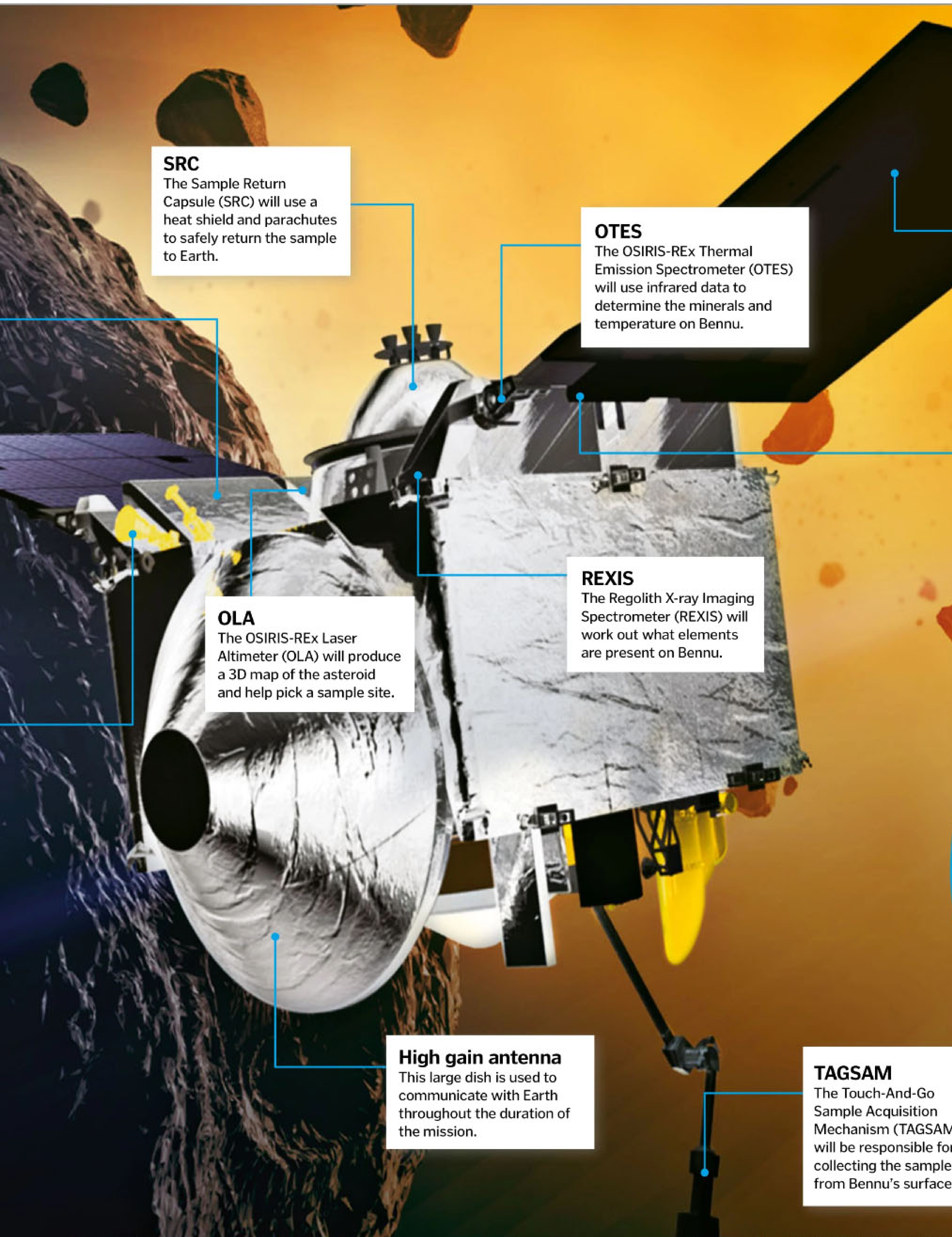
The spacecraft will officially begin its approach to Bennu when it is 2 million kilometres away, by matching the asteroid's speed.



4. Survey
OCTOBER 2018

OSIRIS-REx will start a one-year survey of the asteroid, selecting a suitable site to collect a sample from to bring back.

DID YOU KNOW? *The last US spacecraft to return a sample to Earth was Genesis in 2004, which returned particles of solar wind*



SRC
The Sample Return Capsule (SRC) will use a heat shield and parachutes to safely return the sample to Earth.

OTES
The OSIRIS-REx Thermal Emission Spectrometer (OTES) will use infrared data to determine the minerals and temperature on Bennu.

Solar panels
The spacecraft's two solar panels generate between 1,226 and 3,000 watts, depending on the distance from the Sun.

OCAMS
The three cameras that are in the OSIRIS-REx Camera Suite (OCAMS) will be used to image and map Bennu, as well as record the sampling event.

REXIS
The Regolith X-ray Imaging Spectrometer (REXIS) will work out what elements are present on Bennu.

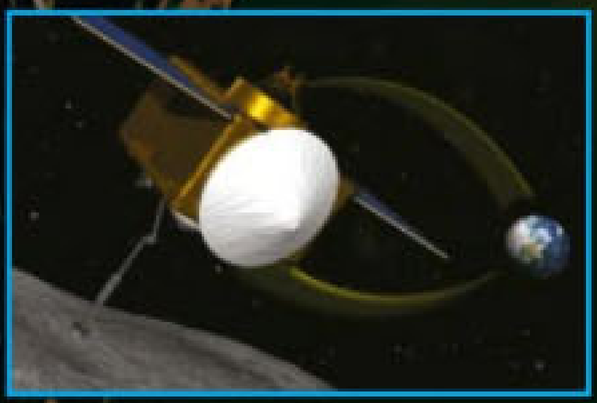
OLA
The OSIRIS-REx Laser Altimeter (OLA) will produce a 3D map of the asteroid and help pick a sample site.

High gain antenna
This large dish is used to communicate with Earth throughout the duration of the mission.

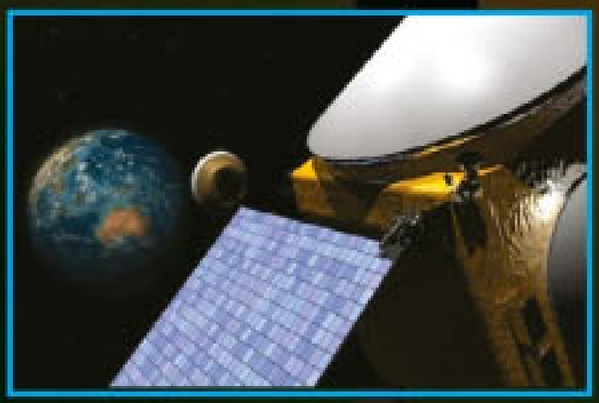
TAGSAM
The Touch-And-Go Sample Acquisition Mechanism (TAGSAM) will be responsible for collecting the sample from Bennu's surface.

OSIRIS-REx launched on 8 September 2016 from Cape Canaveral in Florida

5. Sample collection
3 MARCH 2021
OSIRIS-REx will hover a few metres away from Bennu, extend a robotic arm, and fire three bursts of nitrogen gas to collect a sample.



6. Return
OCTOBER 2018
With the sample safely stowed in a capsule, OSIRIS-REx will now begin its journey back to Earth. It will have a long way to go.



7. Ejection
24 SEPTEMBER 2023
Four hours before re-entry, OSIRIS-REx will jettison its return capsule to journey alone. The spacecraft will be manoeuvred to orbit the Sun.

8. Landing
24 SEPTEMBER 2023
The capsule will free-fall before deploying a parachute at an altitude of 3,000m, bringing it to a soft landing in the Utah desert.

9. Research
BEYOND SEPTEMBER 2023
Scientists will open the capsule, and study samples for organic compounds and clues to our own beginnings.

© NASA; WIKI

Inside Spaceport America

In the town of Truth Or Consequences is the world's first commercial spaceport

Spaceport America is described as the world's "first purpose-built commercial spaceport". It is an impressive 10,000-square-metre terminal building with a 3,657-metre runway, nestled in the remote Jornada del Muerto desert basin in New Mexico, US. Its ambitious organisation is on a mission "to make space travel as accessible to all as air travel is today".

The $200 million facility was designed by UK-based Foster and Partners, and funded by New Mexico state taxpayers. It was built to mirror the spacecraft that it will one day house, with a curved outline, skylights, and a three-storey glass front looking out over the taxiway.

The airport's hangar is known as the Gateway to Space building

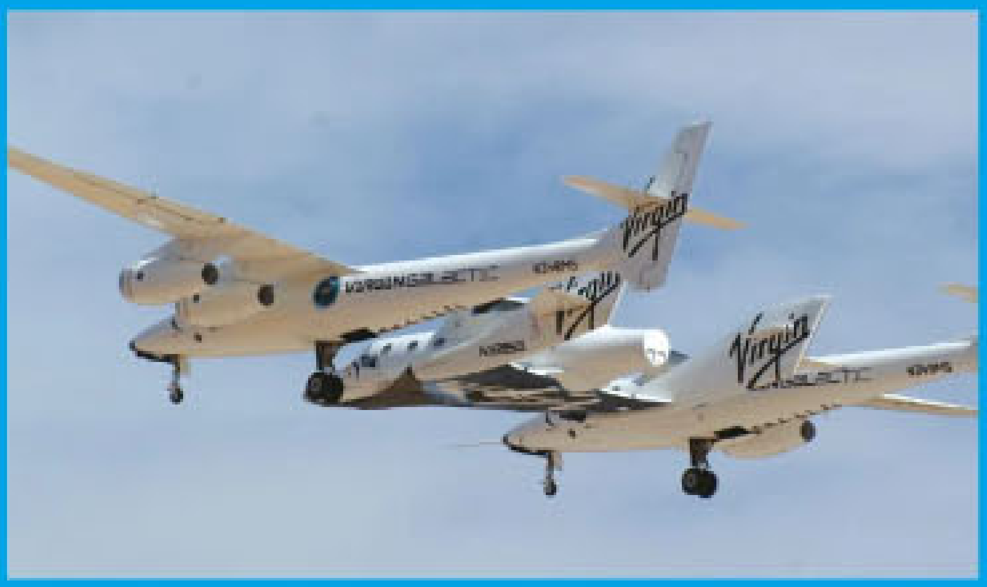
The structure sinks down into the ground to maximise energy efficiency, and winds whistle through to control the temperature inside. Like a standard airport, it has hangars and a departure lounge, but it is also fitted out with a control room, space for astronauts to don their suits, and training facilities for flight preparations to be carried out.

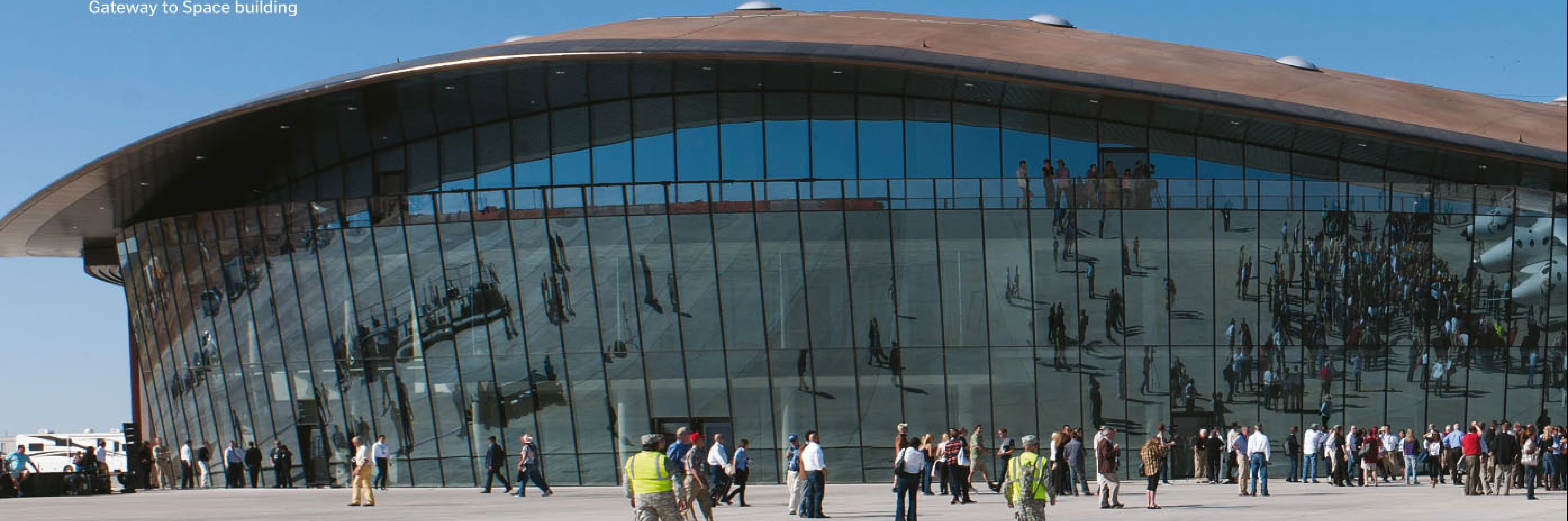
The spaceport officially opened in 2011, with Virgin Galactic signing a 20-year agreement as the primary tenants back in 2008. However, it has been a slow start for this ground-breaking project. Virgin Galactic plans to use the facility to take passengers into space onboard SpaceShipTwo, but after a tragic fatal accident in 2014, the project is now running several years behind schedule.

A number of smaller private companies have paid to use the facilities and over 20 launches have been made, but this is far fewer than originally expected, and the building is losing money. Time will tell whether Spaceport America will achieve its dream of becoming a bustling hub for commercial space travel. For now, it seems that while the building is ready, the spacecraft aren't quite prepared for take-off.

Catching a spaceplane

In the future, it is hoped that Spaceport America will be the top destination for tourists looking to catch a glimpse of the world from outer space. Virgin Galactic intends to prep their would-be astronauts with an intense three-day training course on site. Health and safety is a priority, with emergency response taking the number one spot on their planned training protocol. Medics will also be on hand, to ensure that passengers are physically and mentally ready for the intense experience of the space environment. They will be exposed to g-forces in simulators and light aircraft in preparation for the big day. Once the trip is over, SpaceShipTwo will land on the runway like an airplane, and the passengers will be able to celebrate in style back at the spaceport.


Virgin Galactic's WhiteKnightTwo will help launch SpaceShipTwo into space

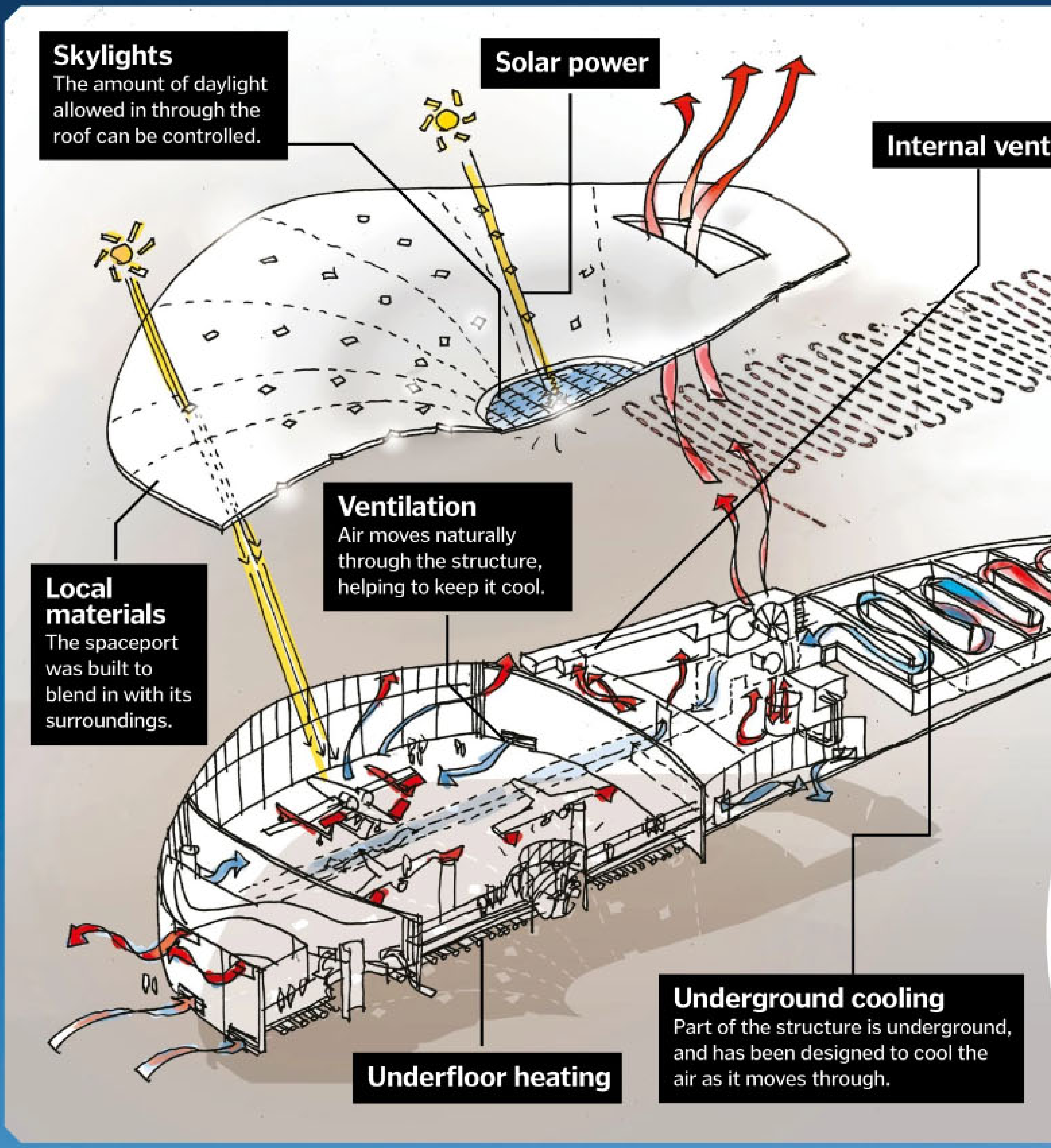


The runway is almost 4km long

DID YOU KNOW? *There are plans to build a British spaceport, with locations being considered in Scotland, Wales and Cornwall*

Building the spaceport

British company Foster and Partners designed Spaceport America to be energy efficient



Skylights
The amount of daylight allowed in through the roof can be controlled.

Solar power

Internal vents

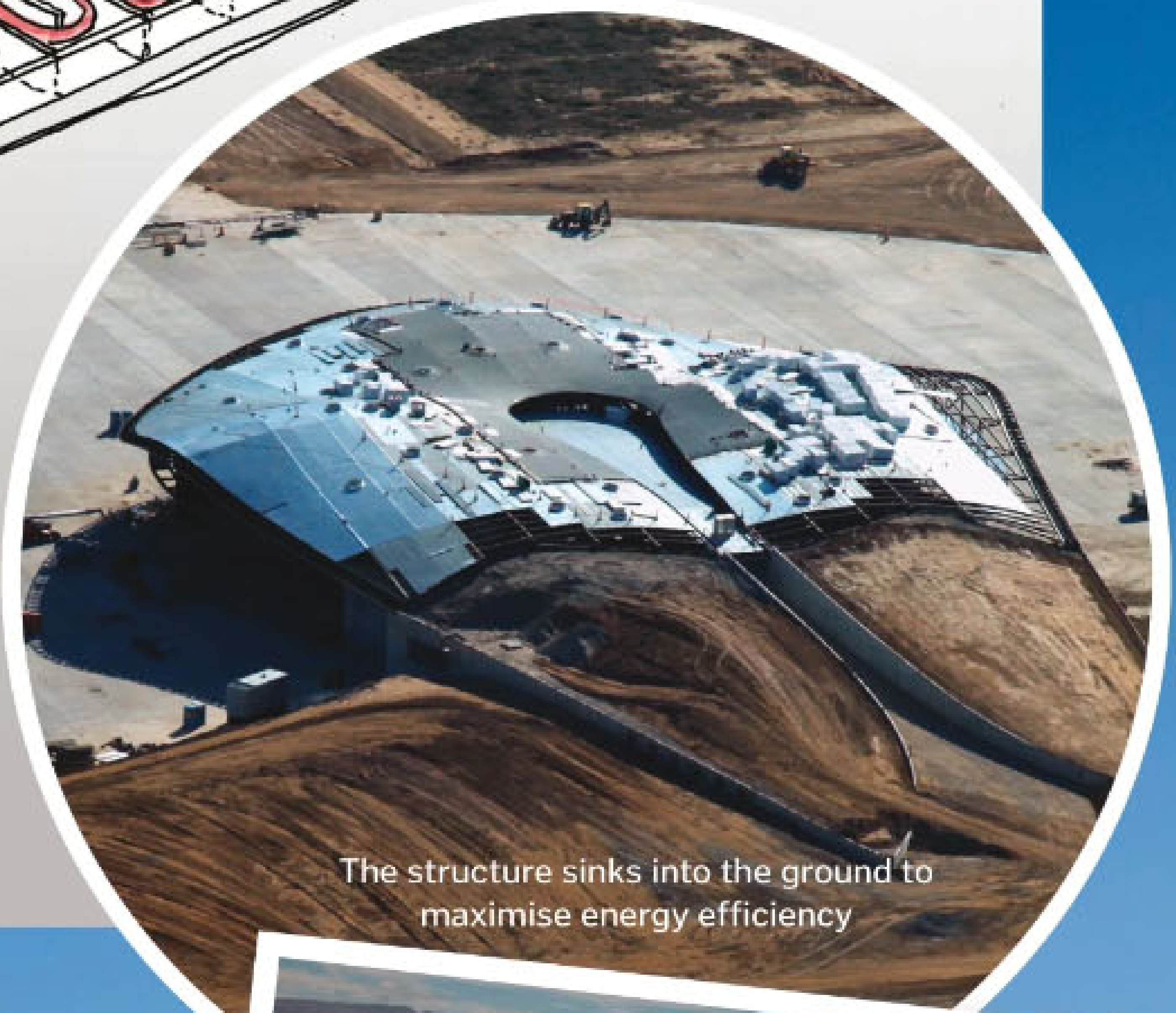
Ventilation
Air moves naturally through the structure, helping to keep it cool.

Local materials
The spaceport was built to blend in with its surroundings.

Underground cooling
Part of the structure is underground, and has been designed to cool the air as it moves through.

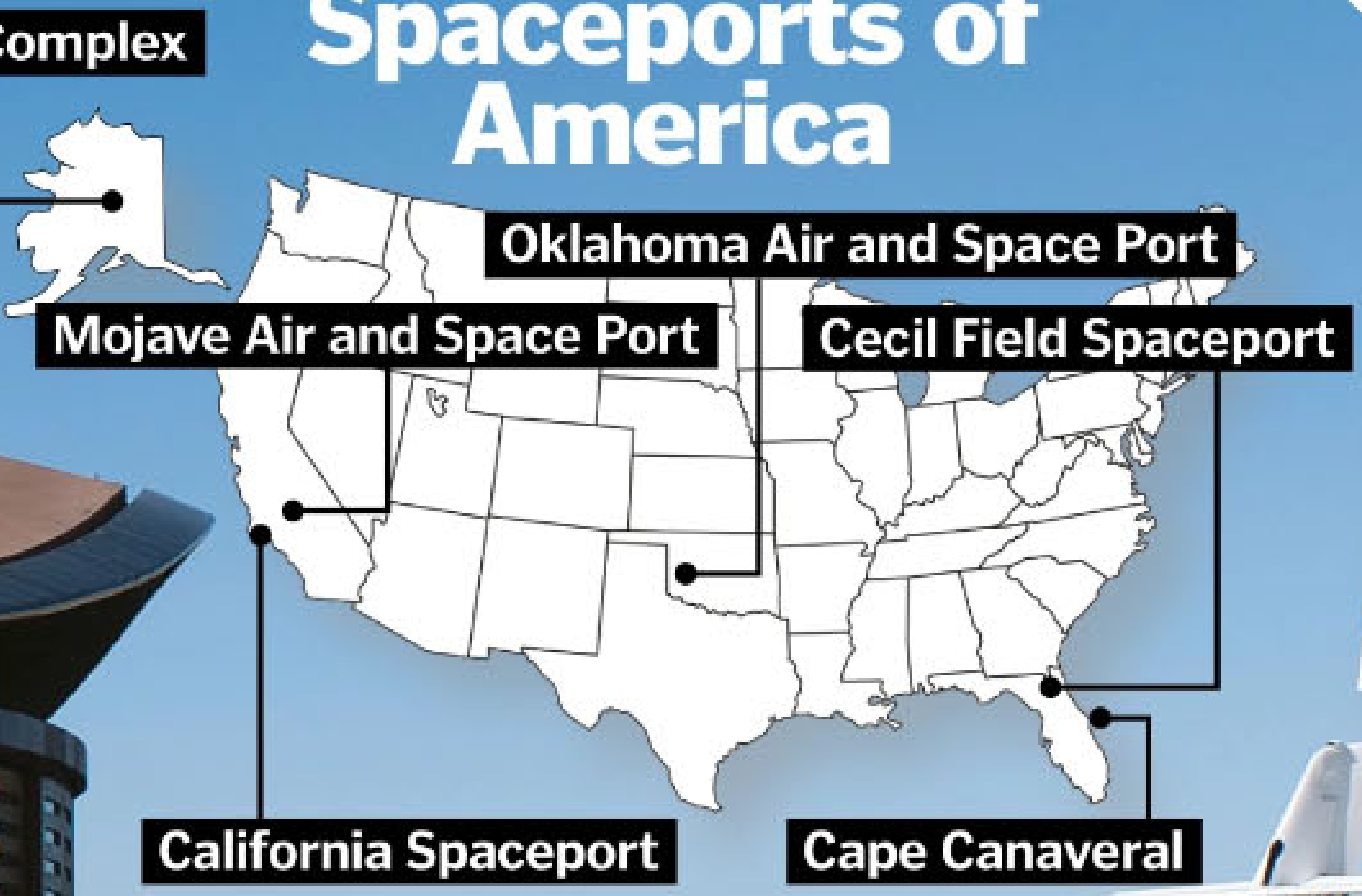
Underfloor heating

© WIKI; Spaceport America; Illustration by Foster + Partners



The structure sinks into the ground to maximise energy efficiency

Spaceports of America



"Like a standard airport, the spaceport has hangars and a departure lounge"

A TRAVELLER'S GUIDE TO THE SOLAR SYSTEM

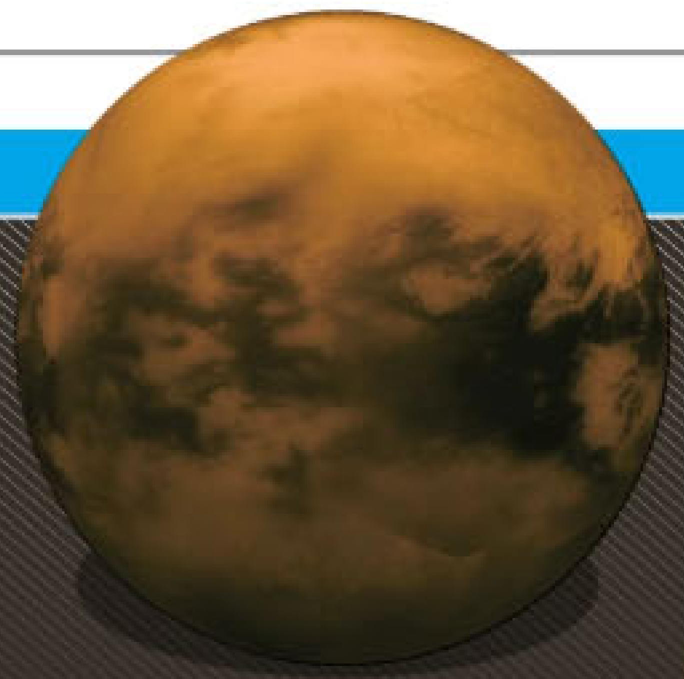
Join us as we embark on an epic voyage to the must-see sights

Today, space travel is the reserve of multibillion dollar national space agencies and private companies. But in the not too distant future, it may become much more accessible and even affordable to the average person. In this future, it's unlikely space travel will have changed too much, barring a major breakthrough. Astronauts will probably still launch into space on rockets, or maybe spaceplanes, and journeys around the Solar System will still rely on using gravitational assists from other planets to reach far-flung destinations. But some dreamers imagine that we might have large habitats traversing the Solar System, which would-be space tourists could hitch a ride on to visit cosmic destinations.

There's certainly no shortage of fascinating places waiting to be explored. Relatively nearby, both Mars and Venus possess features that make them almost Earth-like – and others that make them certainly not. Further out, some of the icy moons of Jupiter and Saturn may have huge underground oceans that could harbour some form of primitive life, while Jupiter itself is fascinating – with a giant storm in its atmosphere that has raged for four centuries.

What would it be like if such destinations were within reach of the average person? Perhaps, as you'll see over the next few pages, we would have tourist brochures describing some of the fantastic holidays you could venture on. So join us as we step into the future to see what the vacations of tomorrow might look like.

DID YOU KNOW? *In 1995, the Galileo Probe was sent into Jupiter's atmosphere – and was crushed in just 78 minutes*



TITAN

An Earth-like alien world

Journey time: **Six years**
Nearby destinations:
Saturn, Enceladus, Mimas
Average temperature:
-180 degrees Celsius

Tired of Earth's poisoned waters and polluted skies? Why not come and see the only other world with lakes and seas on its surface? On Saturn's moon Titan, you'll see oozing bodies of liquid methane as they shimmer on the surface. The largest sea, Kraken Mare, covers 400,000 square kilometres – more than the Caspian Sea here on Earth. It's so thick that it almost looks solid, with the biggest waves only reaching 1.5 centimetres high. Don't fall in by mistake!

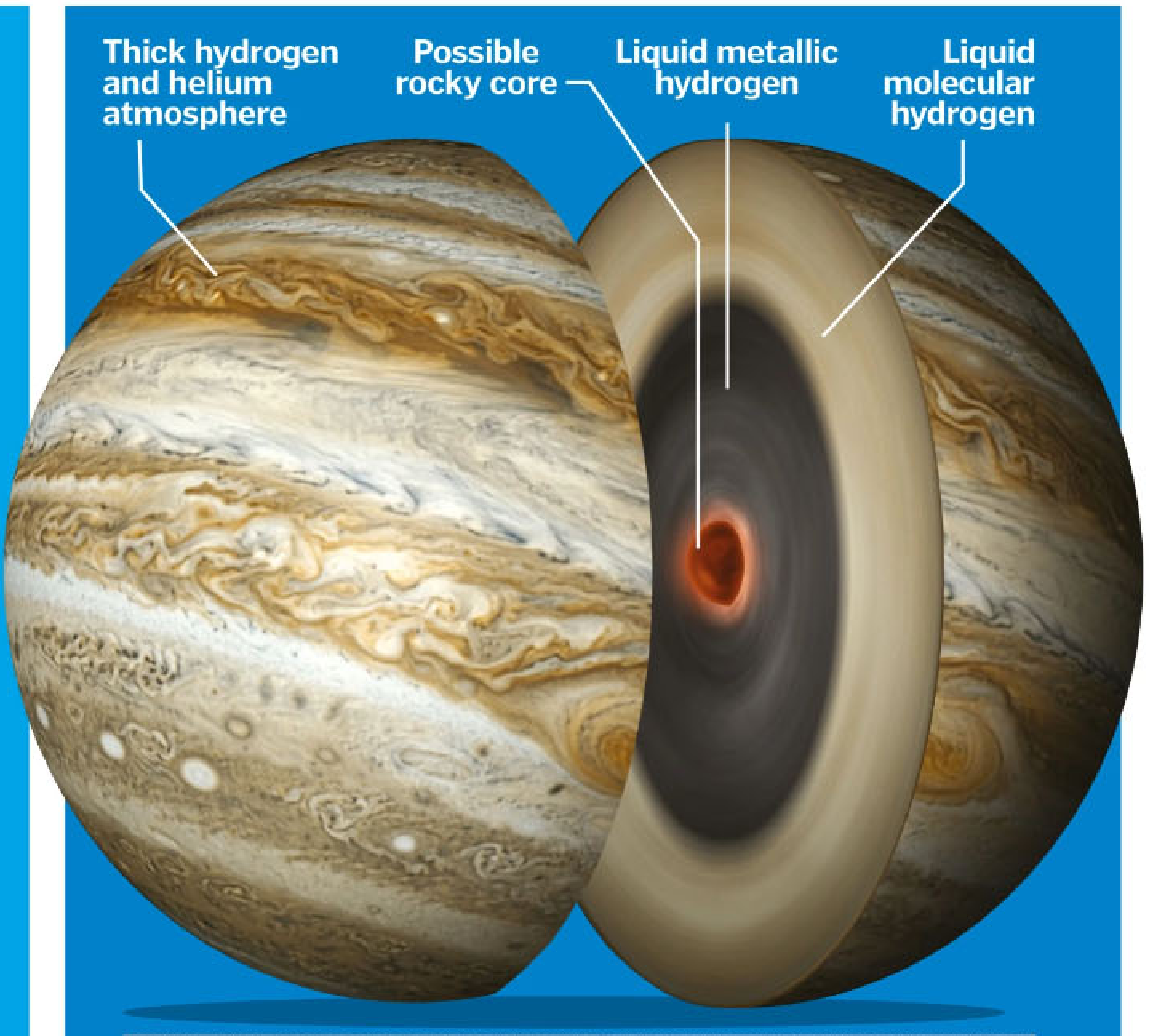
TITAN
RIDE THE TIDES THROUGH THE THROAT OF KRAKEN

Above you, you'll be treated to the most Earth-like weather climate in the Solar System – apart from Earth, of course. On our planet, water is cycled from the ground to the atmosphere, but on Titan, there's methane rain. However, plan your trip wisely, as it only rains once every 1,000 years.

Perhaps best of all, you'll get to experience the moon's surface. From wind-swept sand dunes to the frozen, icy plains, take your time to explore this strange and alien landscape on the trip of a lifetime. If you're lucky, you'll even get to see the first man-made spacecraft to ever touch down on the surface – the Huygens lander – which arrived back in 2005.

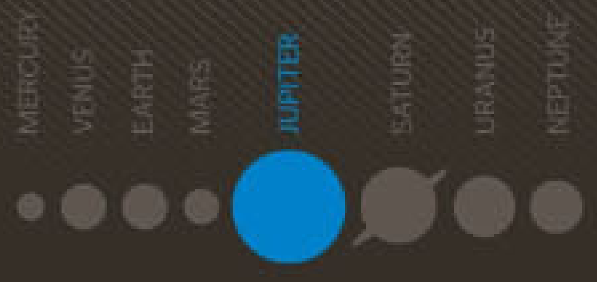
Wrap up warm
Temperatures on Titan's surface fall to -180°C – look out for rocks of ice and liquid methane!

Titan's methane cycle is remarkably similar to Earth's water cycle


Thick hydrogen and helium atmosphere
Possible rocky core
Liquid metallic hydrogen
Liquid molecular hydrogen

JUPITER

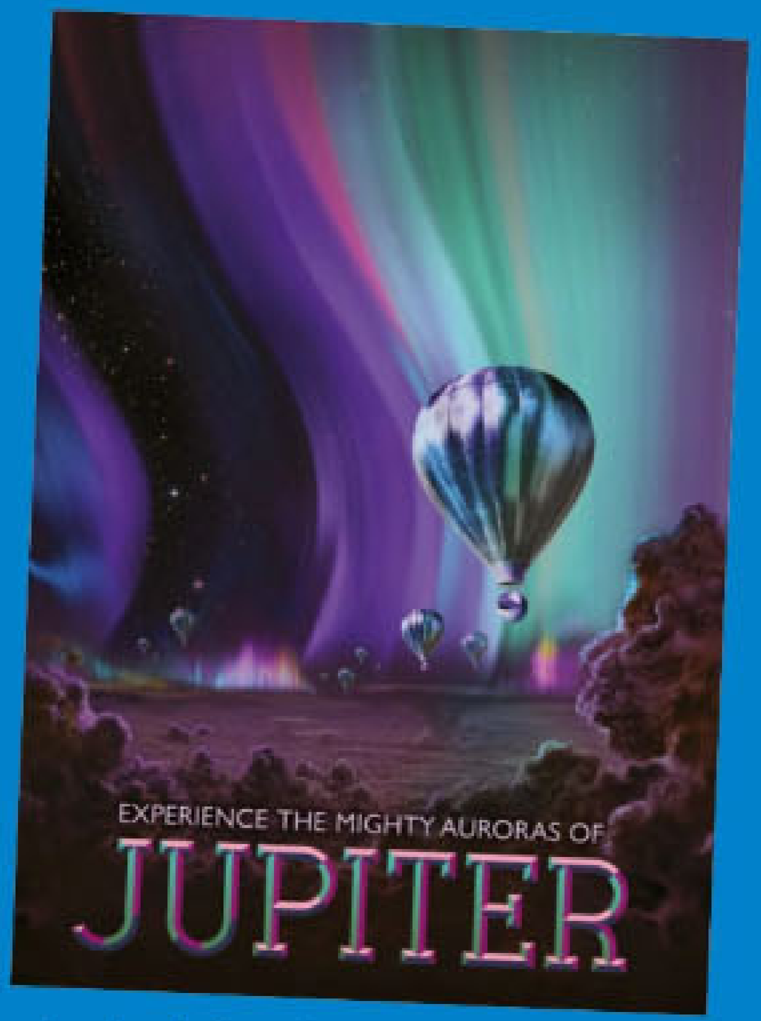
Eye of the storm



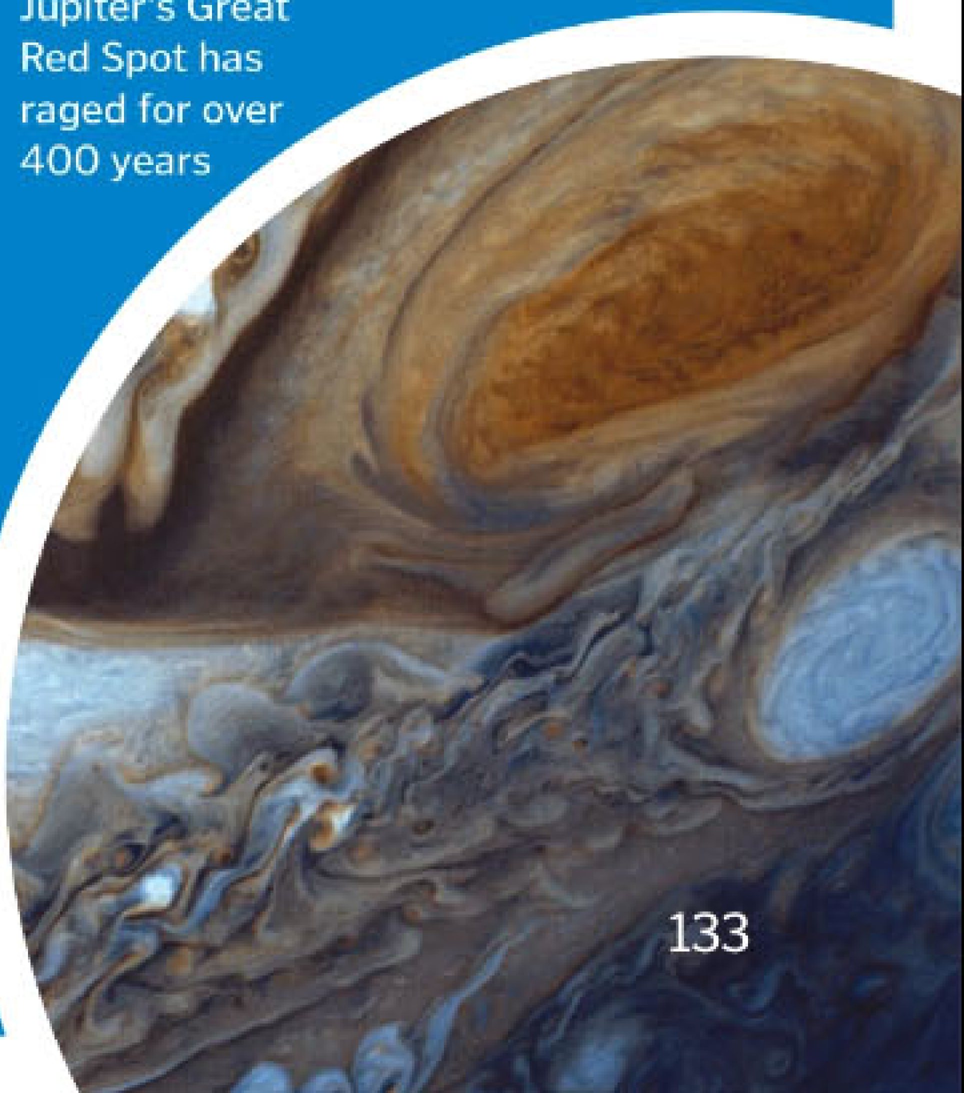
Journey time: **Five years**
Nearby destinations:
Europa, Ganymede, Io
Average temperature:
-145 degrees Celsius

With a storm that has raged for over 400 years and lightning bigger than anything on Earth, you better book soon or miss out! Welcome to Jupiter, the largest planet in the Solar System. This gas giant has a thick atmosphere of hydrogen and helium, with a liquid metallic hydrogen core lying beneath. The pressure there is two million times stronger than the surface pressure on Earth, so you won't be leaving the spaceship – you'd be crushed before you had your complimentary cocktail.

A highlight will be the Great Red Spot, a giant anti-cyclone that has raged since the 17th century. Three Earths would fit inside the storm and the lightning is 1,000 times more forceful than that on our planet. What's more, Jupiter's powerful magnetic field creates fantastic aurorae at its poles that are bigger than the entire Earth.


EXPERIENCE THE MIGHTY AURORAS OF
JUPITER

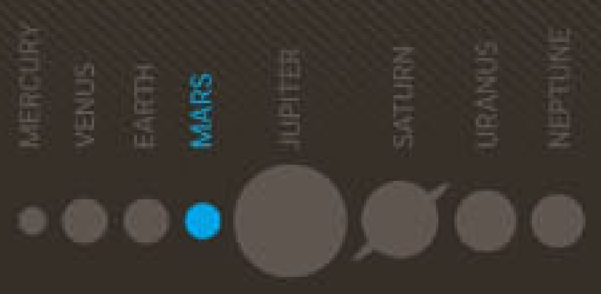
© NASA; Hubble Heritage



Jupiter's Great Red Spot has raged for over 400 years

MARS

Look into our future

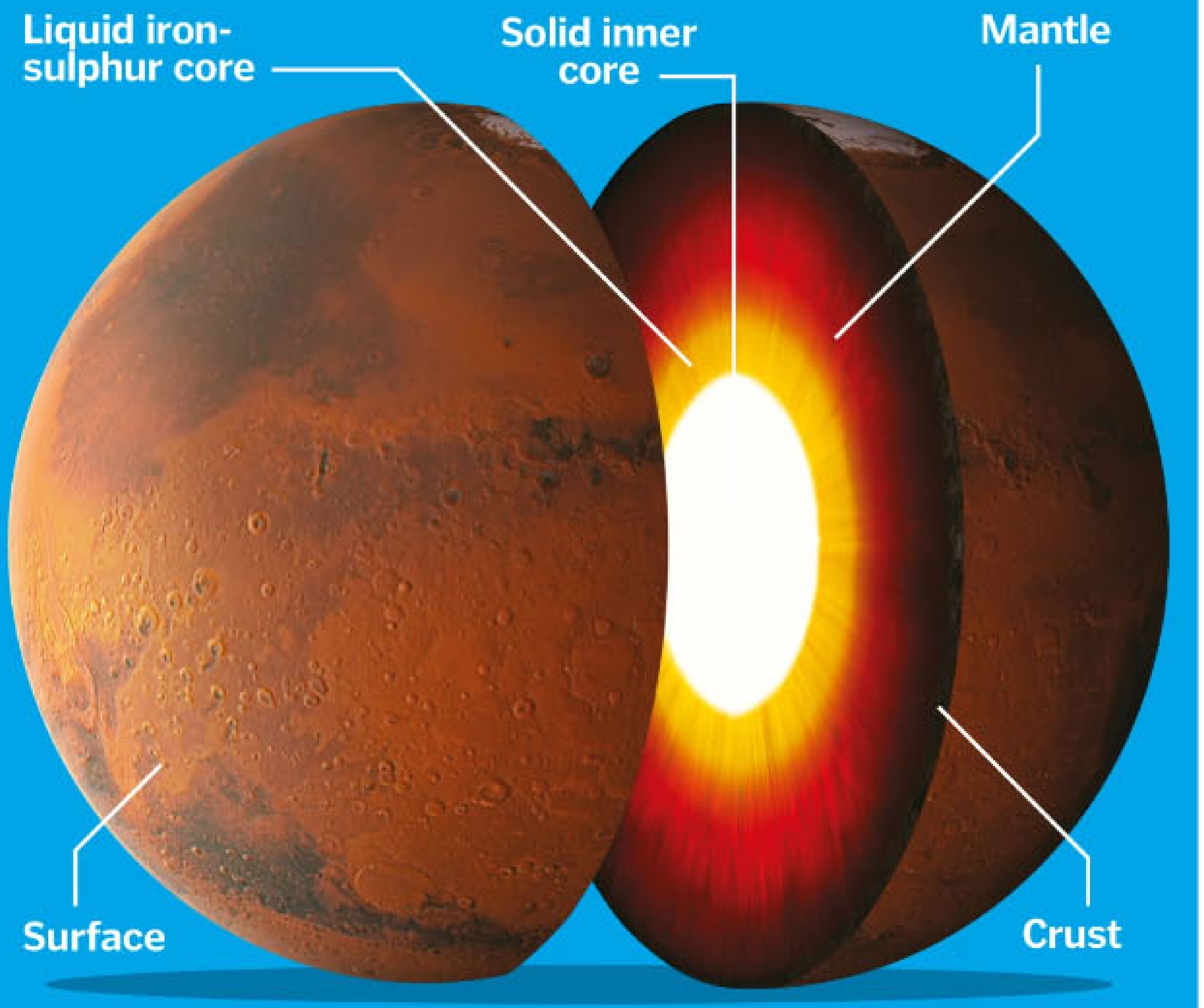


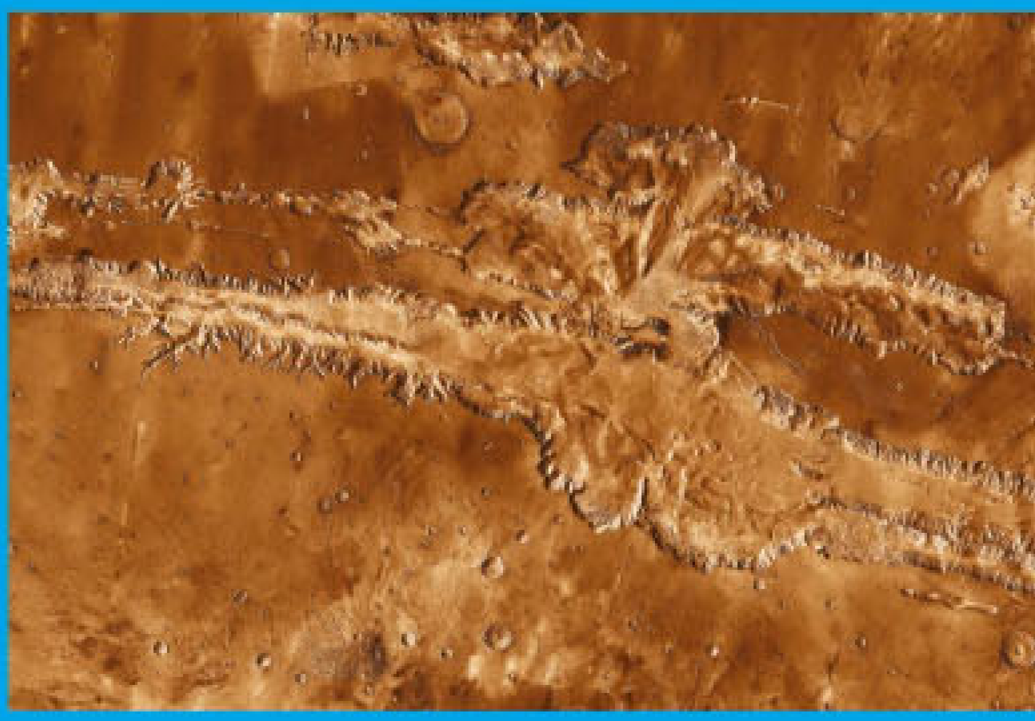
Journey time: **Eight months**
Nearby destinations:
Phobos, Deimos
Average temperature:
-55 degrees Celsius

We haven't got round to inventing time travel yet, but we've got the next best thing: a glimpse of what will become of Earth in a few billion years. This is Mars, a world that once played host to vast oceans and seas, but is now barren and dry as its atmosphere was stripped away by the Sun. On a trip to Mars, you can explore the ancient river and stream beds, remnants of a much more Earth-like past.

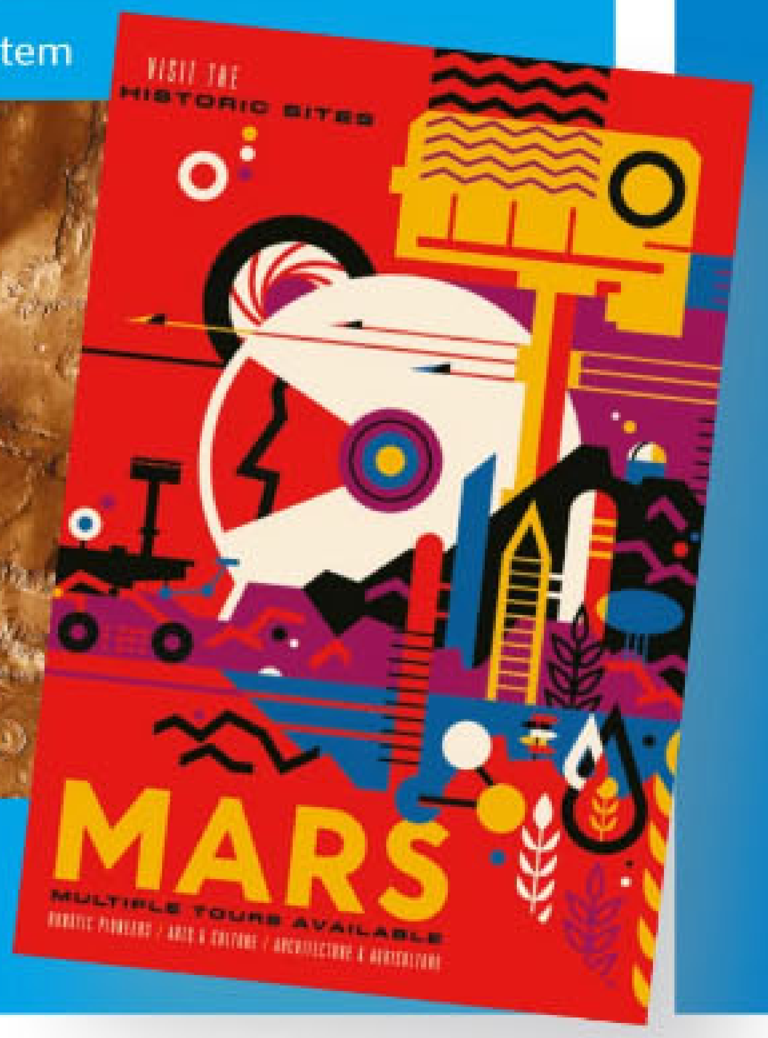
That's not all. Stretching across the equator of Mars is a vast canyon system known as Valles Marineris. It is 4,000 kilometres long – nearly ten times the length of the Grand Canyon – making it the biggest in the Solar System.

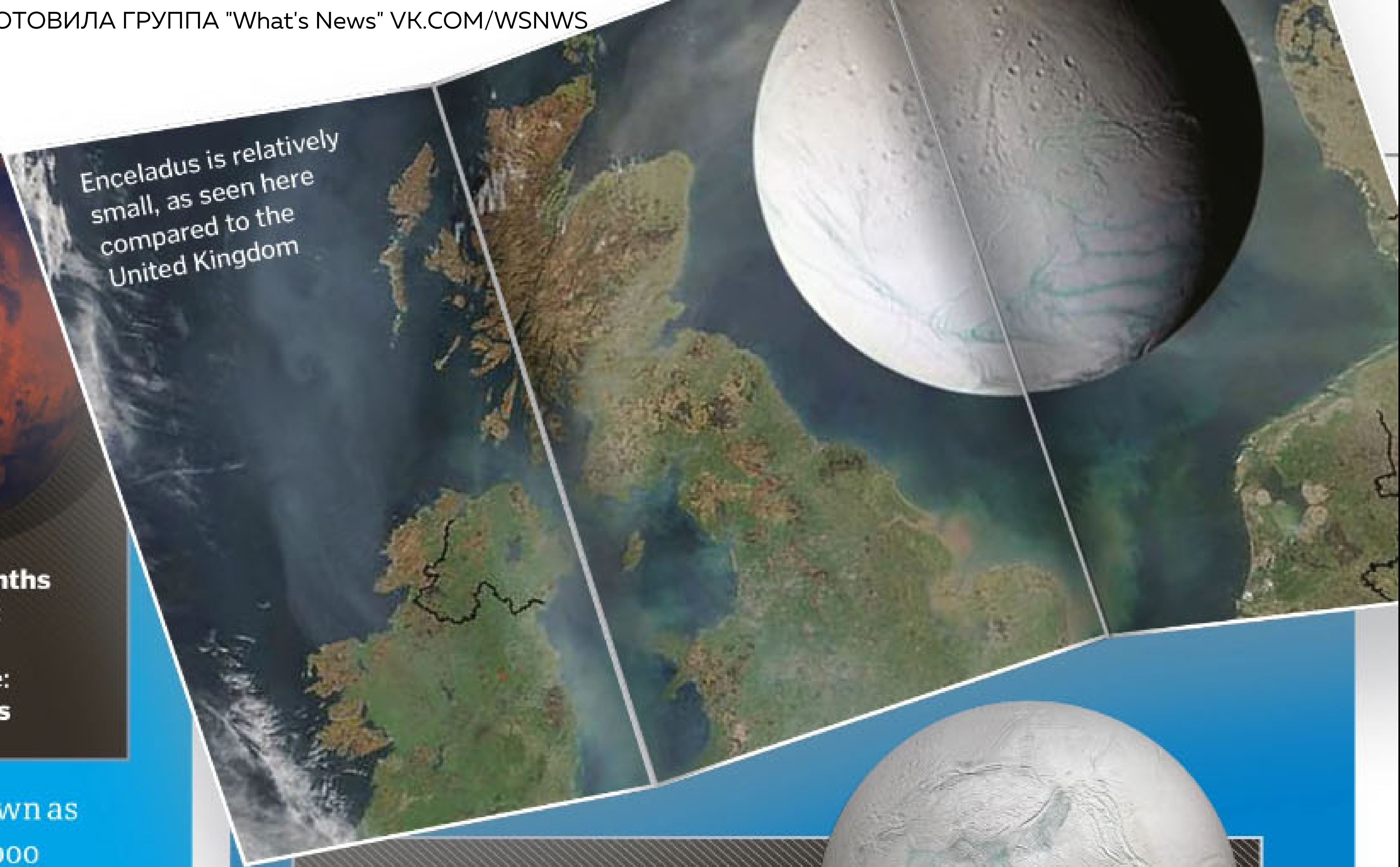
Elsewhere on Mars, you can also visit the largest mountain, Olympus Mons. Spanning 624 kilometres in diameter, it's roughly the size of Arizona, and a towering 25 kilometres high. You'll need to bring your hiking shoes if you decide to climb this cosmic behemoth.





Valles Marineris is the biggest canyon in the Solar System

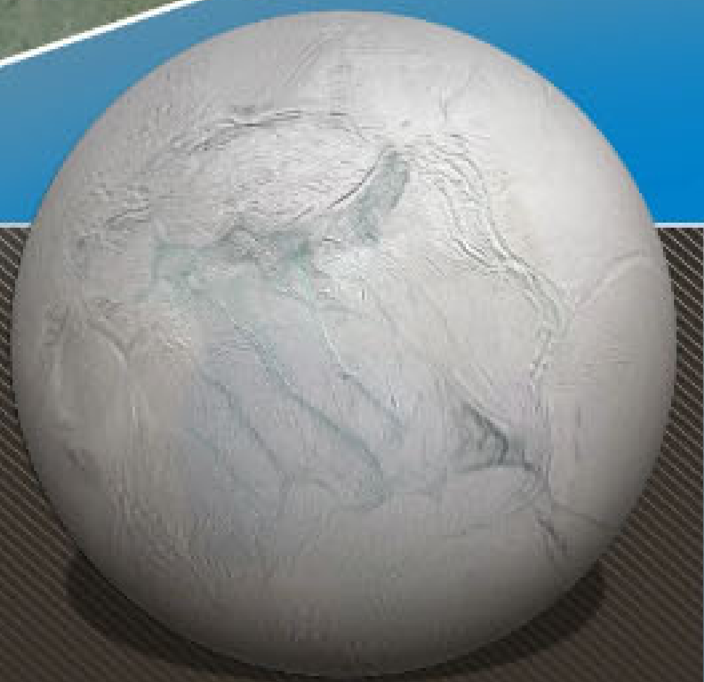




Enceladus is relatively small, as seen here compared to the United Kingdom

ENCELADUS

A world of ice

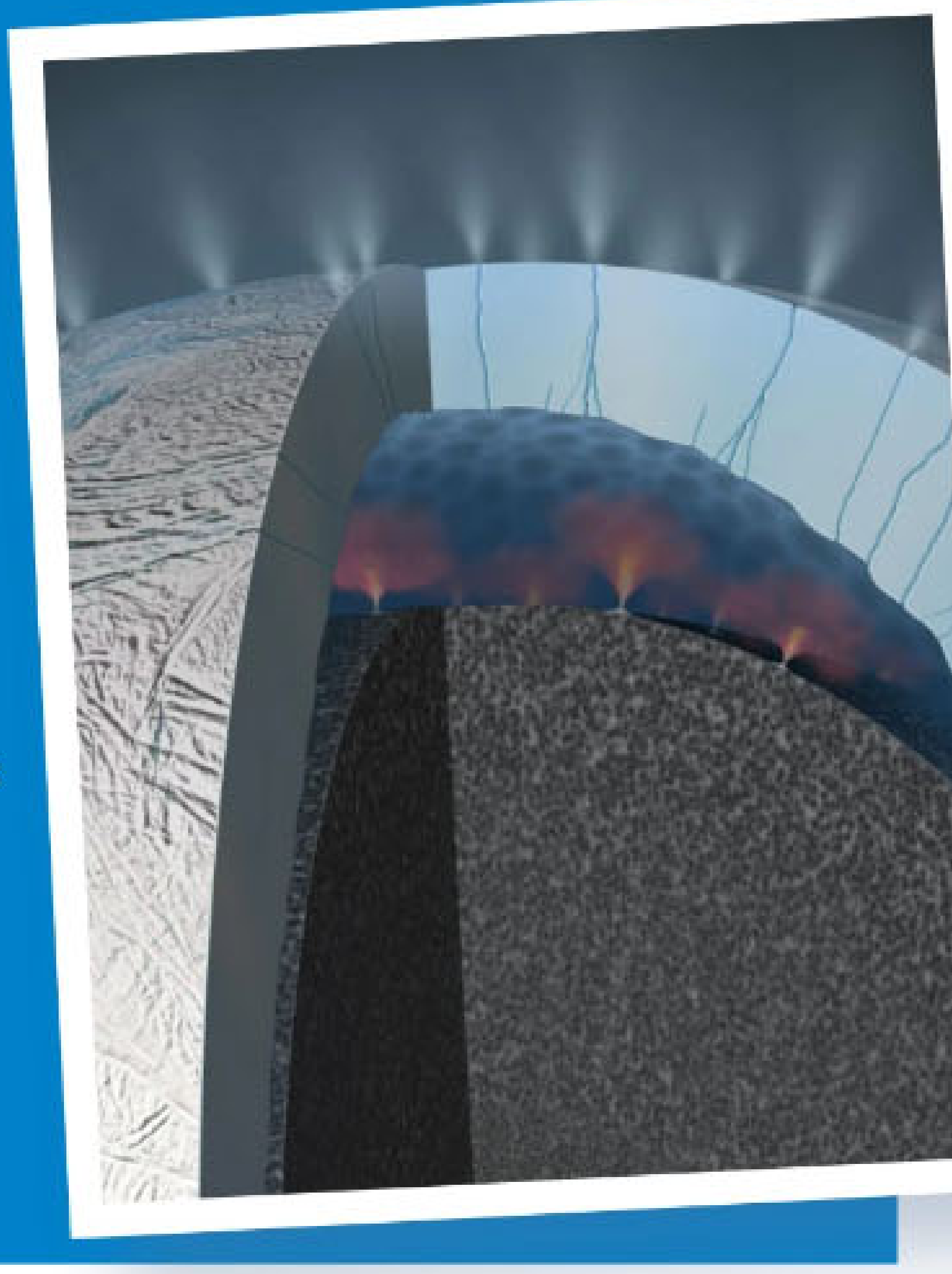


Journey time: **Six years**
Nearby destinations:
Saturn, Titan, Dione
Average temperature:
-200 degrees Celsius

At first glance, you might not be that impressed by Enceladus. Just 500 kilometres in diameter, it is only the sixth largest moon of Saturn, and its surface doesn't look too interesting initially. Peer a little closer, however, and you'll quickly discover a rich and fascinating world. When you arrive at Enceladus, the first thing you'll notice is how bright it is. In fact, it reflects almost all of the sunlight that hits it because the surface is made of ice. It's also dotted with vast canyons up to 200 kilometres long, shaped by tectonic activity in the moon's past.

Perhaps most of interest, though, are the cryovolcanoes – which shoot ice, not lava – near the south pole that are responsible for powering hundreds of geysers. The source of water for these is a vast subsurface ocean, kept wet by the inner heat of Enceladus and tidal forces from another of Saturn's moons, Dione. Small though it may be, this moon is full of surprises. And who knows what lies beneath the surface? Some say the conditions may be right for some form of primitive life to exist.

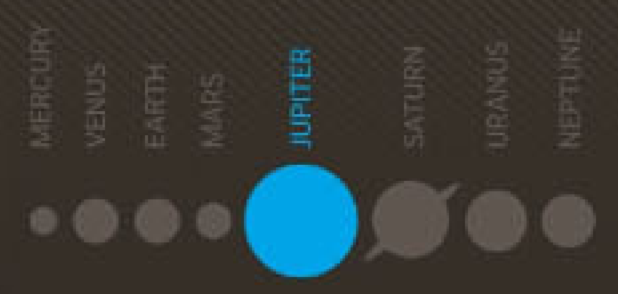
Large geysers of water vapour fire out from the south pole of Enceladus



DID YOU KNOW? *Like Mars, Venus may have had Earth-like bodies of liquid, such as oceans, on its surface billions of years ago*

EUROPA

Search for life



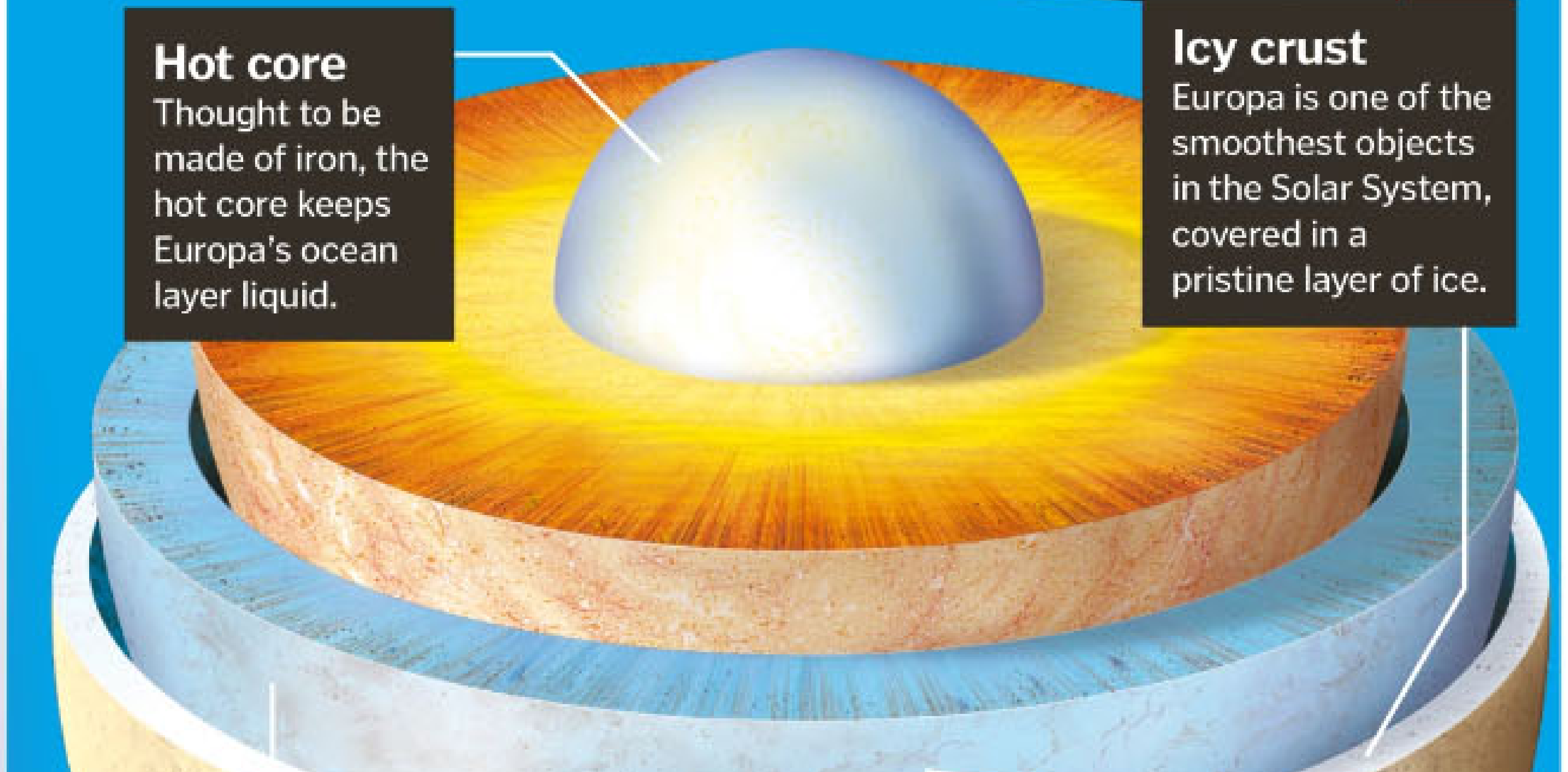
Journey time: **Five years**
Nearby destinations:
Jupiter, Ganymede, Io
Average temperature:
-160 degrees Celsius

As far as we're aware, we're still alone in the universe. But one of our best bets for finding life on a world other than Earth may be Europa, the fourth largest moon of Jupiter. And you, too, could be part of an exciting discovery.

On Europa, you'll orbit Jupiter once every 3.5 days, with the same face of the moon always pointing towards the gas giant. But the orbit of Europa is elliptical, so it is pushed and pulled by the massive planet. This heats its core and, beneath the icy surface, allows a vast ocean, containing more water than there is on Earth, to exist. This source of heat, coupled with the existence of water, suggests the interior of Europa might be habitable.

On the surface, things are no less fascinating. Like Enceladus, Europa may also be ejecting plumes of water into space, but it is the ground itself that is especially interesting. Lines criss-cross beneath your feet, where the icy surface has been pulled apart, revealing warmer layers below. Elsewhere, you'll spot so-called 'chaos' regions, where thick and thin ice on Europa have mushed together to produce iceberg-like features that move across the surface.

EUROPA
DISCOVER LIFE UNDER THE ICE

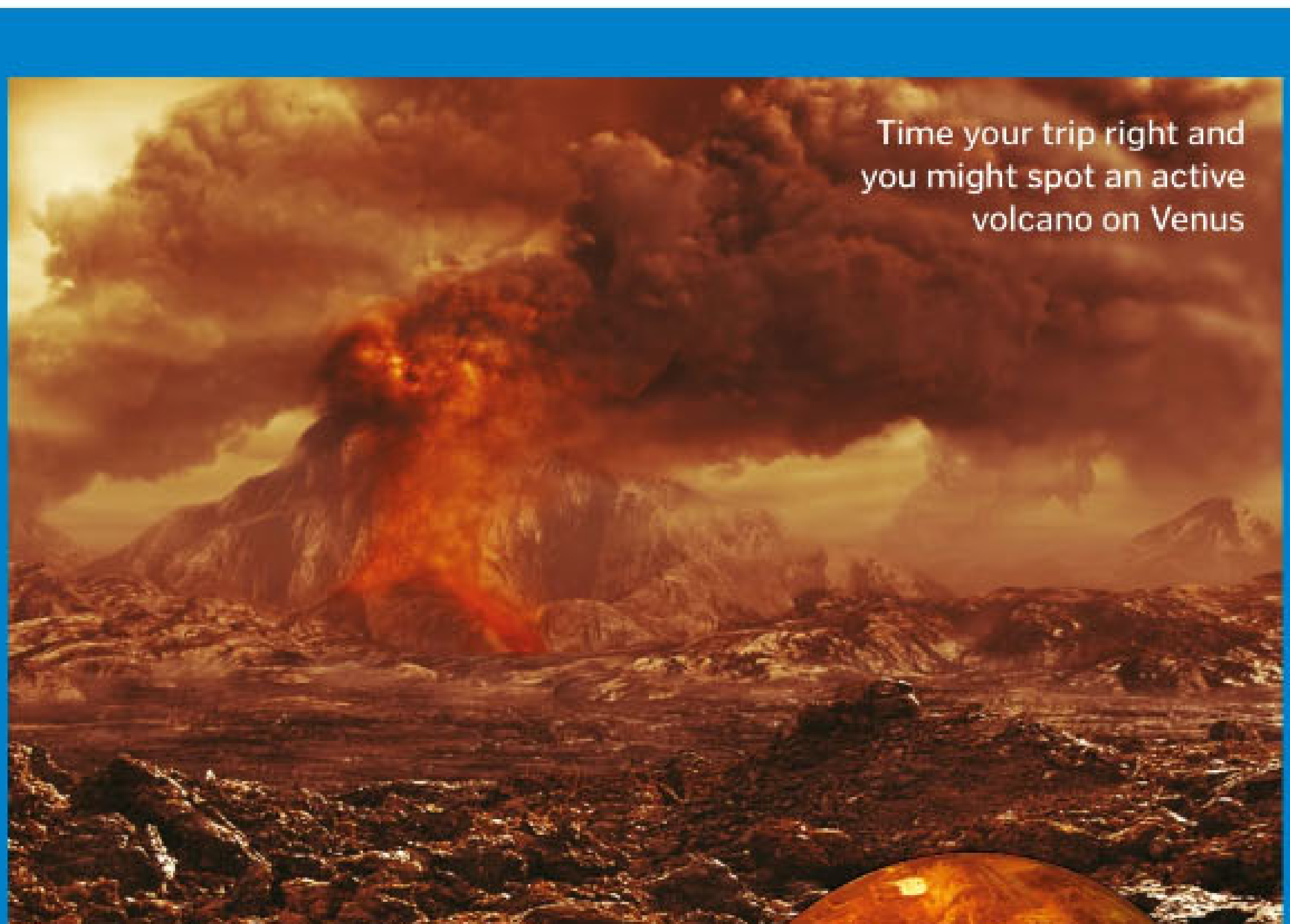


Hot core
Thought to be made of iron, the hot core keeps Europa's ocean layer liquid.

Icy crust
Europa is one of the smoothest objects in the Solar System, covered in a pristine layer of ice.

Hidden ocean
Under Europa's icy surface lies a vast ocean with more water than there is on Earth.

Plumes of water also shoot from Europa, just like Saturn's moon Enceladus



Time your trip right and you might spot an active volcano on Venus

VENUS

Some like it hot

Journey time: **Three months**
Nearby destinations:
Mercury, The Sun
Average temperature:
462 degrees Celsius

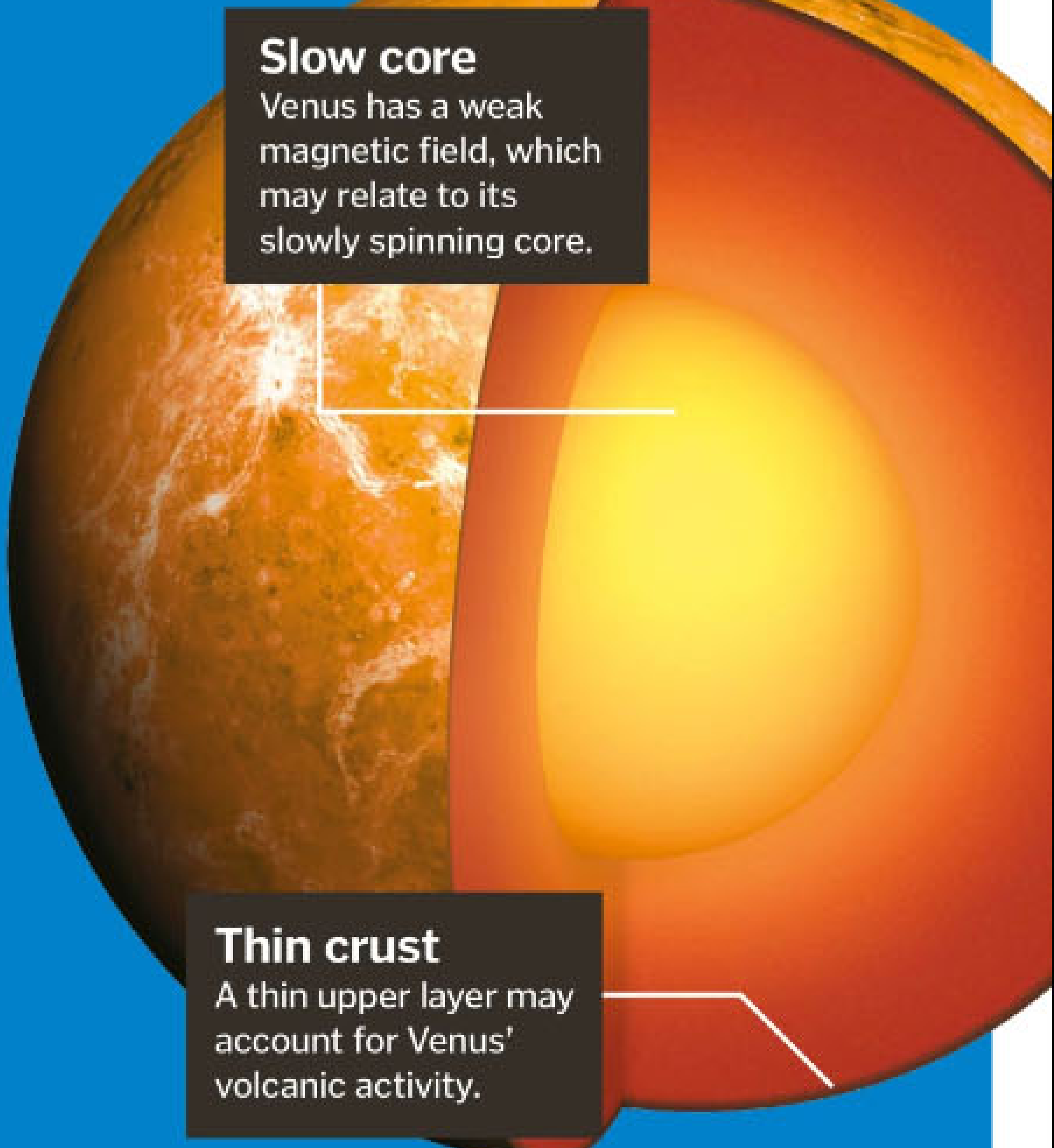
It might be the hottest planet in the Solar System, but don't let that deter you from visiting Venus. Between 50 and 60 kilometres above the surface, you'll find the most Earth-like conditions on any other world, as the atmospheric pressure and temperature are the same as on our planet. Here, you can stay on floating colonies as you enjoy the many wonders of Venus, complete with dramatic forks of lightning striking through the atmosphere.

Down on the surface, things get a little toastier. With a scorching hot temperature of several hundred degrees Celsius – hot enough to melt lead – you won't want to venture down unprotected.

Explore a little and you'll discover many geological features that are also found back on planet Earth. These include huge canyons, volcanoes, and even ancient lava flows.

There are alien features too, though, such as large ring-like structures called crowns – up to 580 kilometres wide – which

© SPL; NASA; ESA



Slow core
Venus has a weak magnetic field, which may relate to its slowly spinning core.

Thin crust
A thin upper layer may account for Venus' volcanic activity.

Growing food on Mars and the Moon could hugely benefit plans to colonise other worlds

Farming on alien planets

Mars and the Moon could be new places to grow food

Believe it or not, the soil found on the Moon and Mars could actually be much more fertile than some of the dirt found on Earth. If we are ever to go on to colonise other worlds – with the Red Planet being our number-one target – then this is very good news for astronauts.

It's thanks to a team of scientists in the Netherlands, who have braved volcanoes in Hawaii and Arizona to obtain material akin to Martian dirt and lunar soil, to provide us with the information that could help humans one day settle on an alien planet. Both soils have the essential ingredients plants need to grow – nitrates and ammonium.

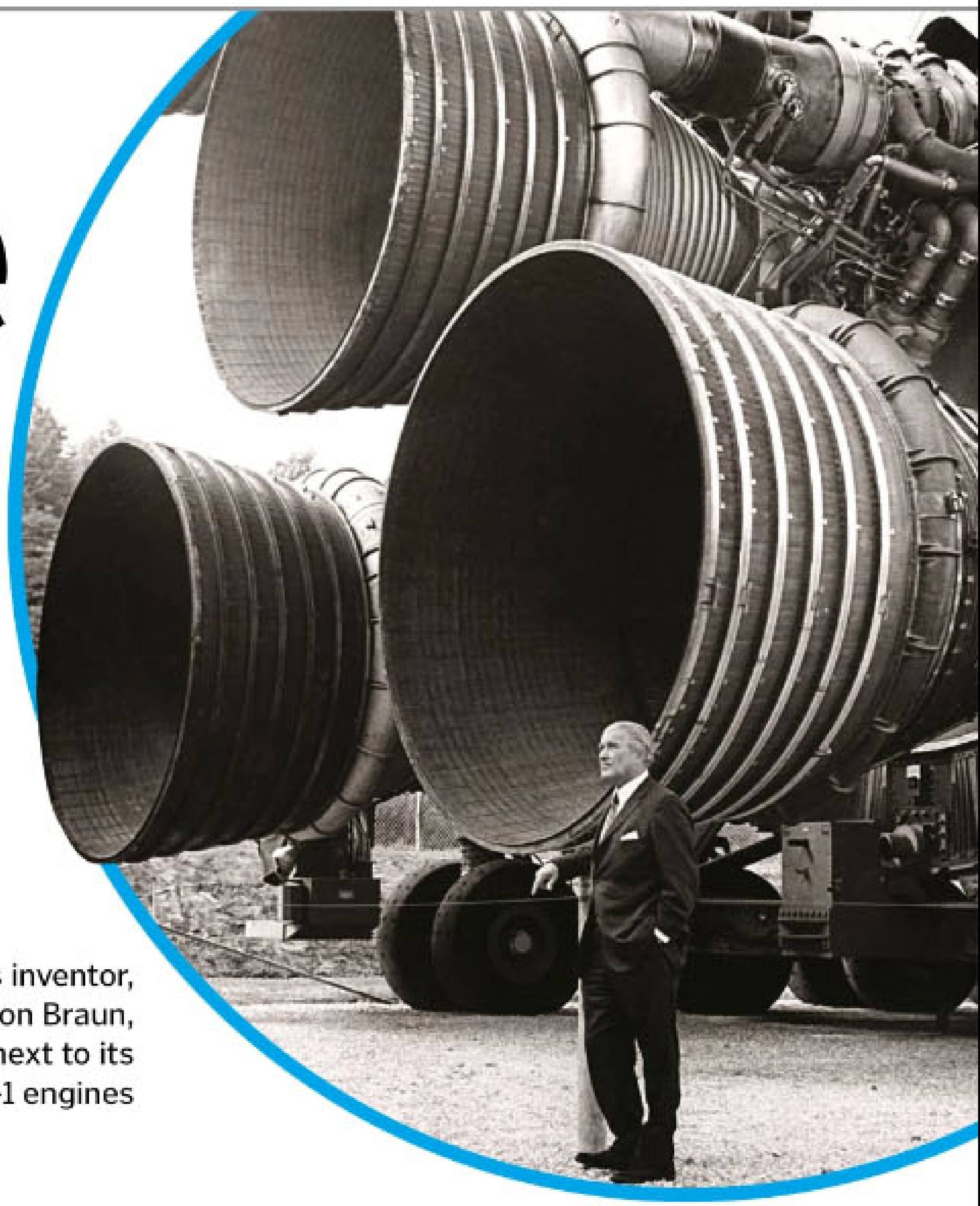
The experts found – by using 'fake' minerals from Mars and the Moon to try and grow carrots, tomatoes, weeds and wheat – that untreated soil found on Mars was the plant's favourite. On the other hand, Moon dirt didn't agree with them completely, with some crops struggling to grow.

All's not lost for crop farming on the Moon, though – scientists think that pumping our natural satellite's soil with nitrogen-fixing bacteria could be the ticket for growing crops on our cratered companion.

© NASA/ESA/The Hubble Heritage Team; NASA

Rockets of the past, present and future

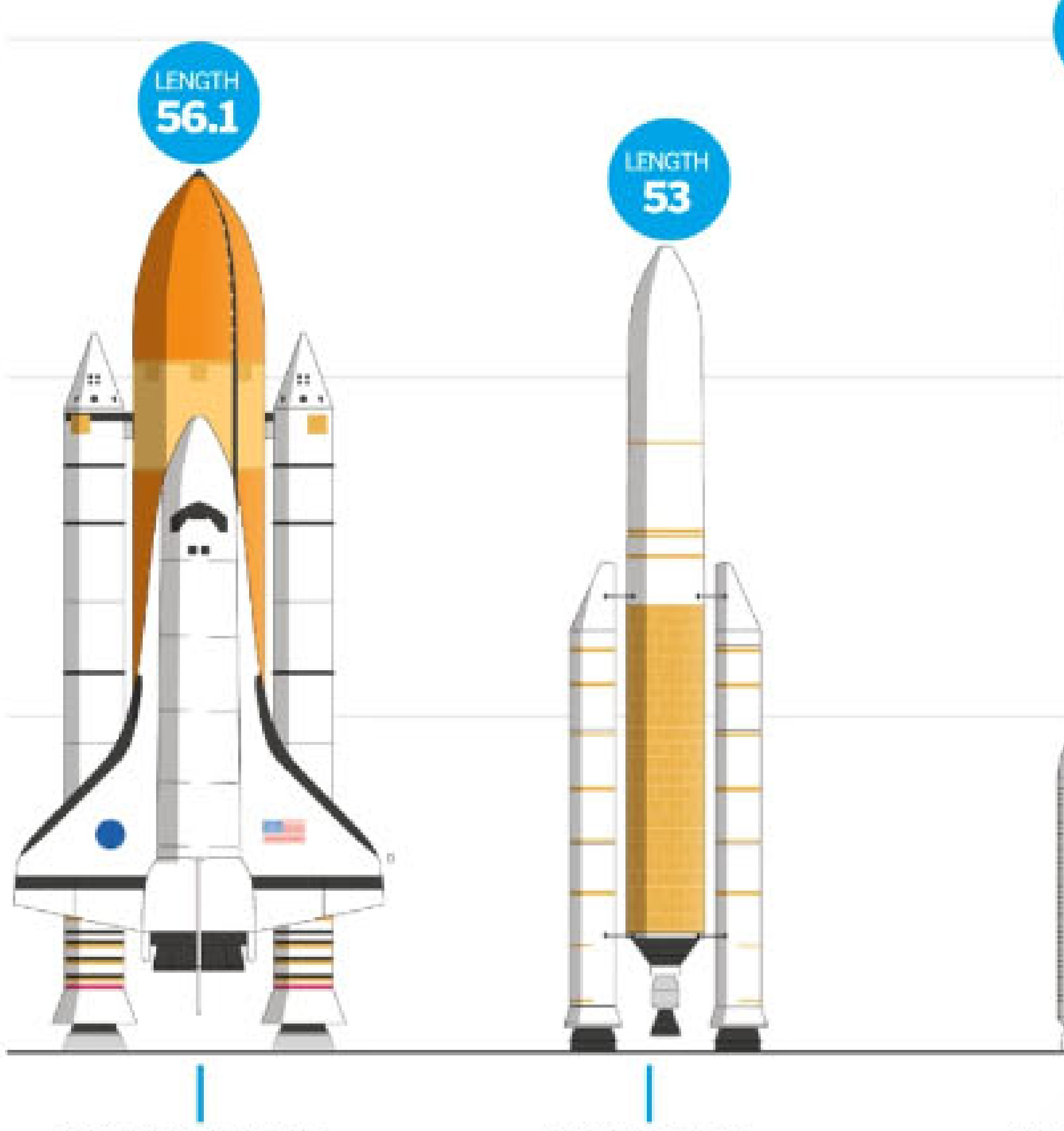
How does NASA's Space Launch System compare with some of history's greatest launchers?

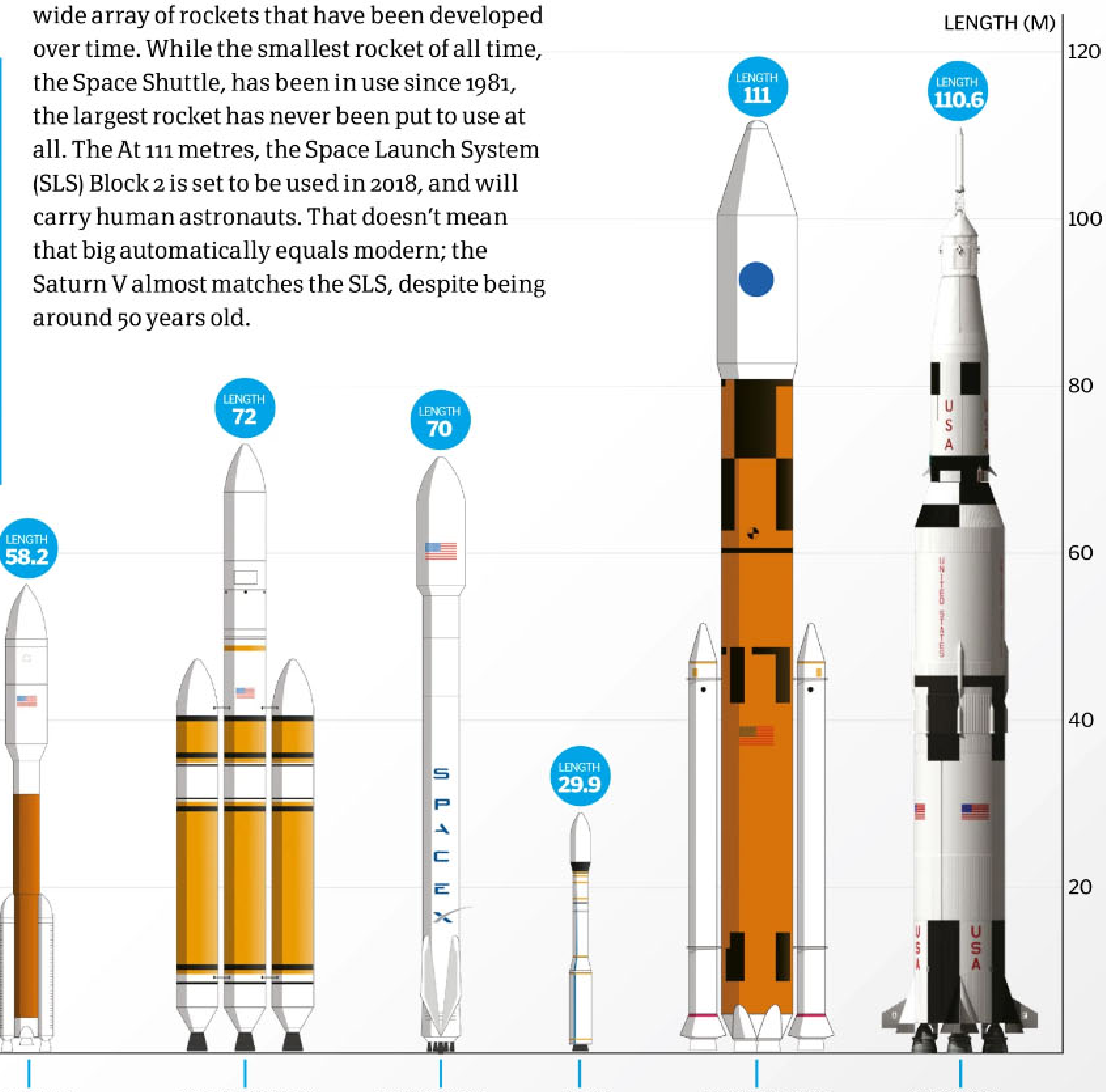


The Saturn V's inventor, Wernher von Braun, stands next to its gigantic F-1 engines

Ever since the words "One small step for man, one giant leap for mankind" echoed from our television sets, space exploration has been pushed to be faster, stronger, and bigger. This can be seen in the wide array of rockets that have been developed over time. While the smallest rocket of all time, the Space Shuttle, has been in use since 1981, the largest rocket has never been put to use at all. The At 111 metres, the Space Launch System (SLS) Block 2 is set to be used in 2018, and will carry human astronauts. That doesn't mean that big automatically equals modern; the Saturn V almost matches the SLS, despite being around 50 years old.

The SLS does lose sections after launch, shortening it





SPACE SHUTTLE
Years of service:
1981-2011
Payload to low-Earth orbit (tons): **27.5**
Cargo: **Satellites, probes and astronauts**
Destinations:
International Space Station, Hubble Space Telescope

ARIANE 5 ES
Years of service:
2008-present
Payload to low-Earth orbit (tons): **21**
Cargo: **Rosetta, Automated Transfer Vehicle**
Destinations:
Geostationary transfer orbit, long term orbit

ATLAS V 551
Years of service:
2006-present
Payload to low-Earth orbit (tons): **18.8**
Cargo: **Juno, New Horizons**
Destinations:
Low-Earth orbit, geostationary transfer orbit

DELTA IV HEAVY
Years of service:
2004-present
Payload to low-Earth orbit (tons): **28.8**
Cargo: **Orion Multi-Purpose Crew Vehicle, Orion satellites**
Destinations: **Low-Earth orbit, geosynchronous transfer orbit**

FALCON 9 V1.1
Years of service:
2015-present
Payload to low-Earth orbit (tons): **13.2**
Cargo:
Communications satellites
Destinations:
Low-Earth orbit

VEGA
Years of service:
2012-present
Payload to low-Earth orbit (tons): **1.5**
Cargo: **Smaller satellites**
Destinations:
Low-Earth orbit, Sun-synchronous orbit, polar orbit

SPACE LAUNCH SYSTEM (SLS) BLOCK 2
Years of service:
From 2018
Payload to low-Earth orbit (tons): **130**
Cargo: **Four astronauts**
Destinations: **Beyond low-Earth orbit, asteroids, Mars**

SATURN V
Years of service:
1967-1973
Payload to low-Earth orbit (tons): **140**
Cargo: **The Apollo missions to the Moon, Skylab space station**
Destinations: **Beyond low-Earth orbit**

LIVING ON THE MOON

How we could turn craters into colonies for human life

The Moon is our closest neighbour, but only 12 people have ever set foot on its surface. Since 1972, the only visitors have been robots, orbiters and probes. For a long time there was little interest in going back, but at just three days journey away from Earth, the Moon is an obvious target for further investigation. With more countries establishing their own space programmes, and an increasing number of private companies entering the field, interest in the Moon is growing once again.

The environment on the Moon's surface is hazardous, but if we can find a way to construct a base we would gain access to a wealth of off-world resources. It is a prime location for telescopes and communications equipment, and its unique environment could hold clues to the history of the Solar System. The Moon's potential has been recognised by organisations across the world, and there are now several exploratory missions in development. At the moment, these are focused around finding out more about the Moon's potential, but over the next few decades, manned missions and even base construction could be on the agenda.

Russia's Roscosmos are planning a series of Luna-Glob missions as a starting point for establishing a robotic base, and in collaboration with the European Space Agency, they are hoping to scope out the Moon's south pole in 2019 and 2020. The China National Space Administration are developing a series of Chang'e probes to collect lunar samples in preparation for future mining missions, and they are building a shuttle capable of lifting human astronauts to the Moon. What's more, in 2007, Google launched the Lunar XPRIZE, encouraging private companies to land rovers on the surface by 2017. Even NASA, who has chosen to focus their resources on manned missions to asteroids and to Mars, are developing a probe to map the water deposits on the lunar south pole.

At the moment, we are just taking our first tentative steps towards further exploration of the Moon, but in the future a science fiction-style base on the surface could become a reality. We explore what such a lunar outpost might look like, and what hazards and challenges could get in the way.

DID YOU KNOW? *The last person to have set foot on the Moon was Apollo astronaut Eugene Cernan in 1972*

Why the Moon?

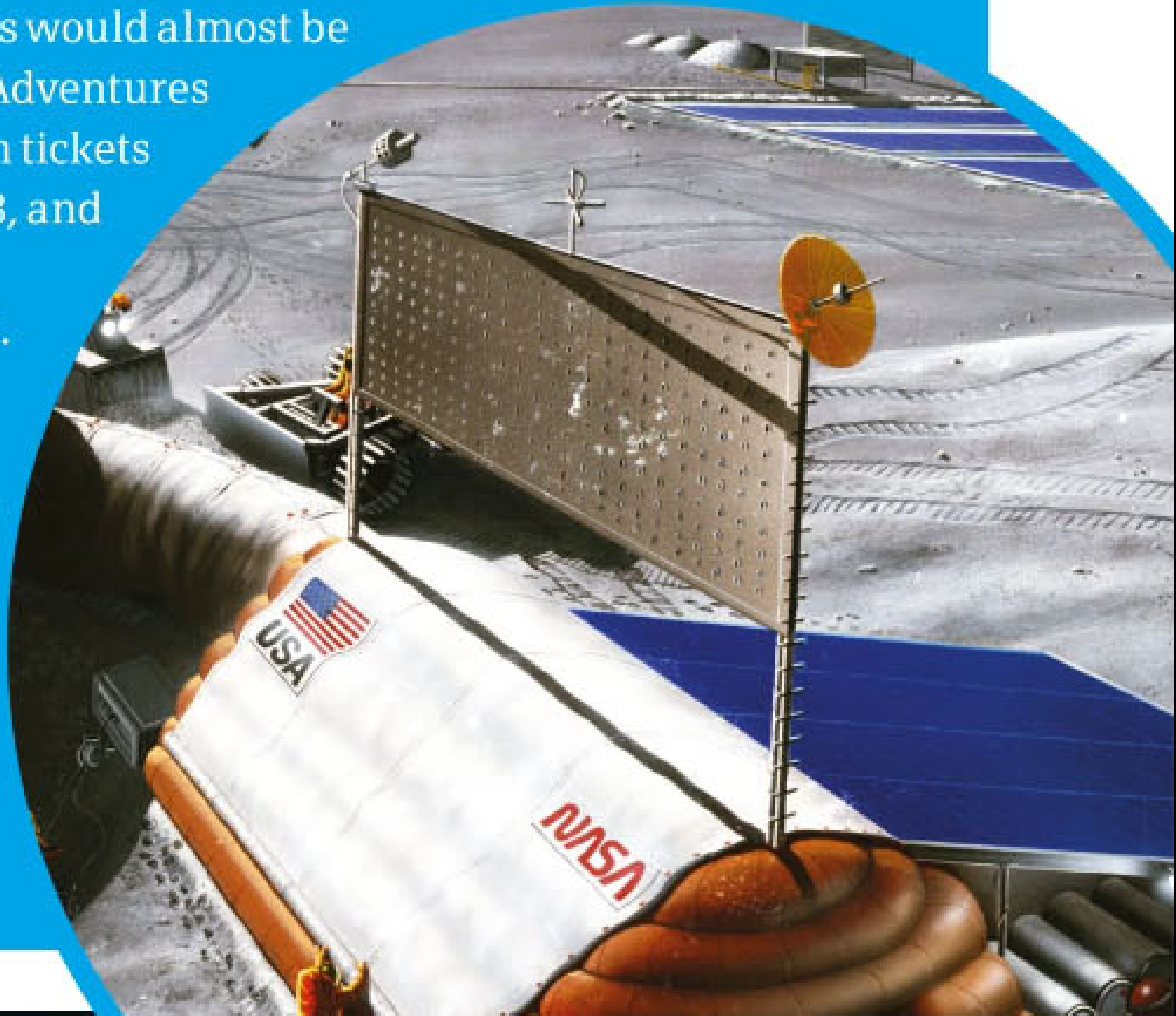
With preparations already underway for manned missions to Mars, some might question the logic behind a return to the Moon, but a lunar outpost could bring several advantages. A trip to the Moon and back could be completed in under a week, and the surface is rich in resources. Lunar dust contains hydrogen, oxygen, iron and other metals, and if these resources could be mined, it could provide a close off-world source of water and building materials.

The far side of the Moon is shielded from the noise of Earth's communications, providing a quiet vantage point for looking out into the universe, and the near side has a constant view of the surface of our planet, making it an ideal place to set up monitoring stations. Navigational support could also be provided for a variety of operations, from search and rescue on Earth to deep space exploration.

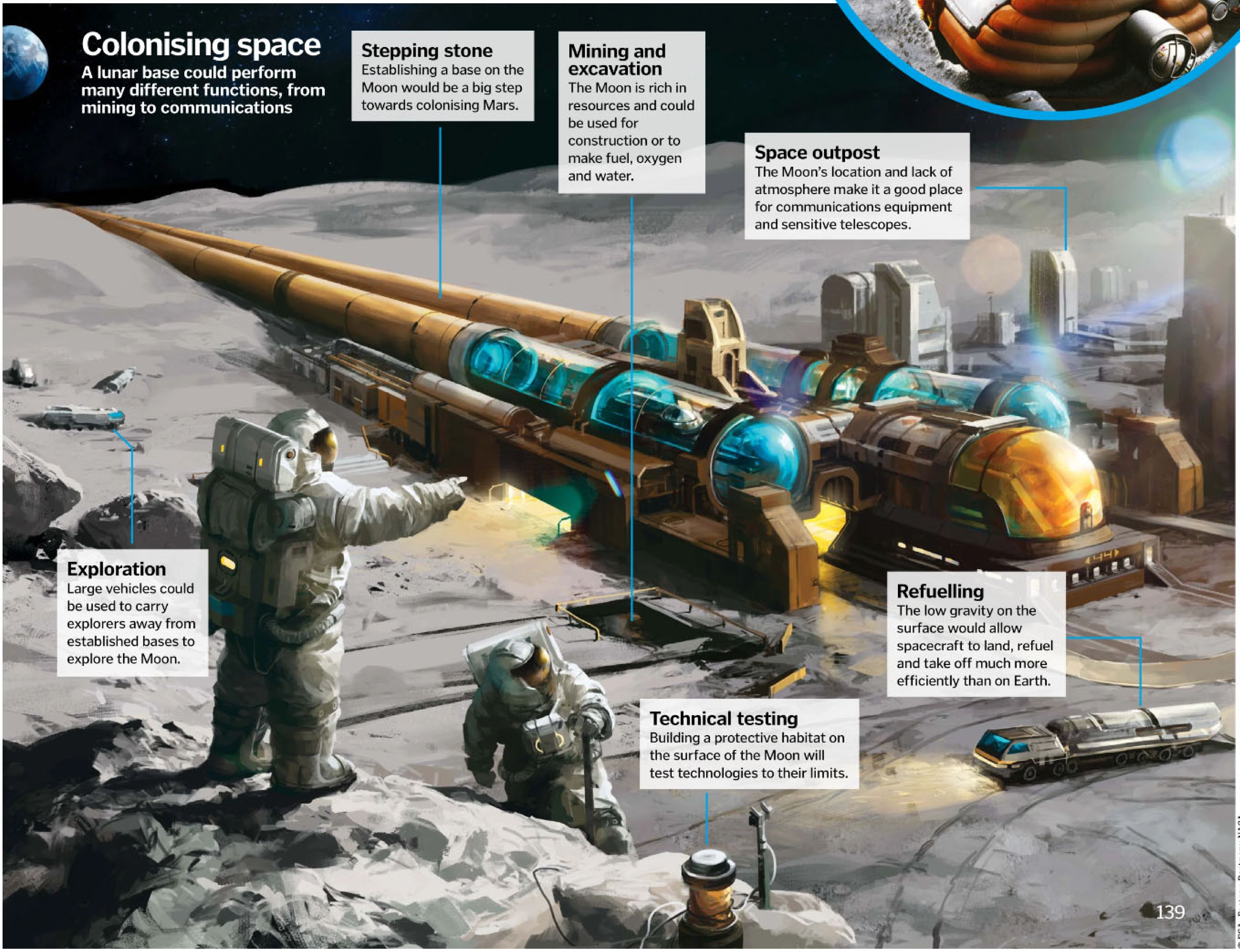
A base on the Moon would also allow us to look closer at its geology, which in turn would help us uncover more about its history and the evolution of the Solar System. Experiments could be conducted, and materials and equipment could be tested, away from the familiar conditions on Earth.

Lunar holidays

With space tourism barely in its infancy, it might seem a bit premature to consider the idea of holidaying on the Moon, but if humanity were to establish a base up there, visitors would almost be inevitable. The company Space Adventures has already sold two $150 million tickets for a trip to visit the Moon in 2018, and more private organisations are looking to set up their own tours. Rules set out in the 1967 Outer Space Treaty state that the Moon cannot be claimed by any country, even if they have set up a base there. However, laws regarding the exploitation of the Moon and its resources for commercial gain have not yet been fully established.



A base on the Moon could pave the way for a new kind of holiday



Colonising space

A lunar base could perform many different functions, from mining to communications

Stepping stone
Establishing a base on the Moon would be a big step towards colonising Mars.

Mining and excavation
The Moon is rich in resources and could be used for construction or to make fuel, oxygen and water.

Space outpost
The Moon's location and lack of atmosphere make it a good place for communications equipment and sensitive telescopes.

Exploration
Large vehicles could be used to carry explorers away from established bases to explore the Moon.

Refuelling
The low gravity on the surface would allow spacecraft to land, refuel and take off much more efficiently than on Earth.

Technical testing
Building a protective habitat on the surface of the Moon will test technologies to their limits.

© ESA_Foster + Partners; NASA

How to build a base

The Moon has little atmosphere and none of the protective shielding that we enjoy here on Earth; as a result, the surface is hostile. It is pummelled by solar winds, scorched by radiation, and chunks of rock regularly fall from the sky. The ground is coated in the shattered remains of ancient asteroid impacts, forming a thick layer of sticky dust, and with no atmosphere or weather to wear the particles down, the grains are razor sharp. A successful base would need protection against all of these threats, and, for people to stay there long-term, it would also require a steady supply of food, water, oxygen, power, shelter and rocket fuel.

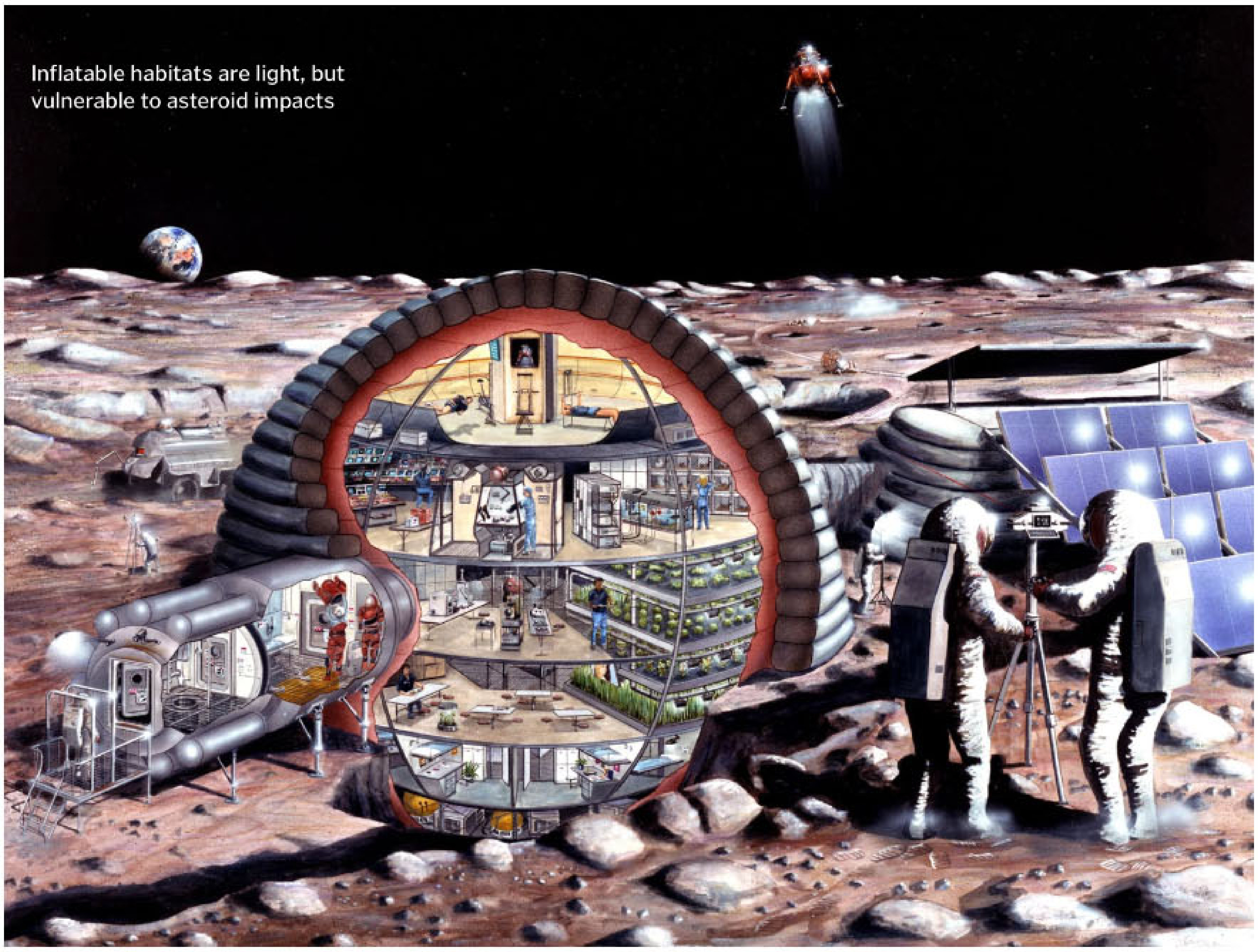
One of the most popular concepts for a lunar base is inflatable housing – lightweight and easily assembled by pressurising from the inside. With the airlock from the landing capsule used as a door, these structures could provide a quick and simple solution to setting up a base. However, a puncture could prove catastrophic, so the pods would need to be shielded in underground chambers or beneath piles of Moon dust.

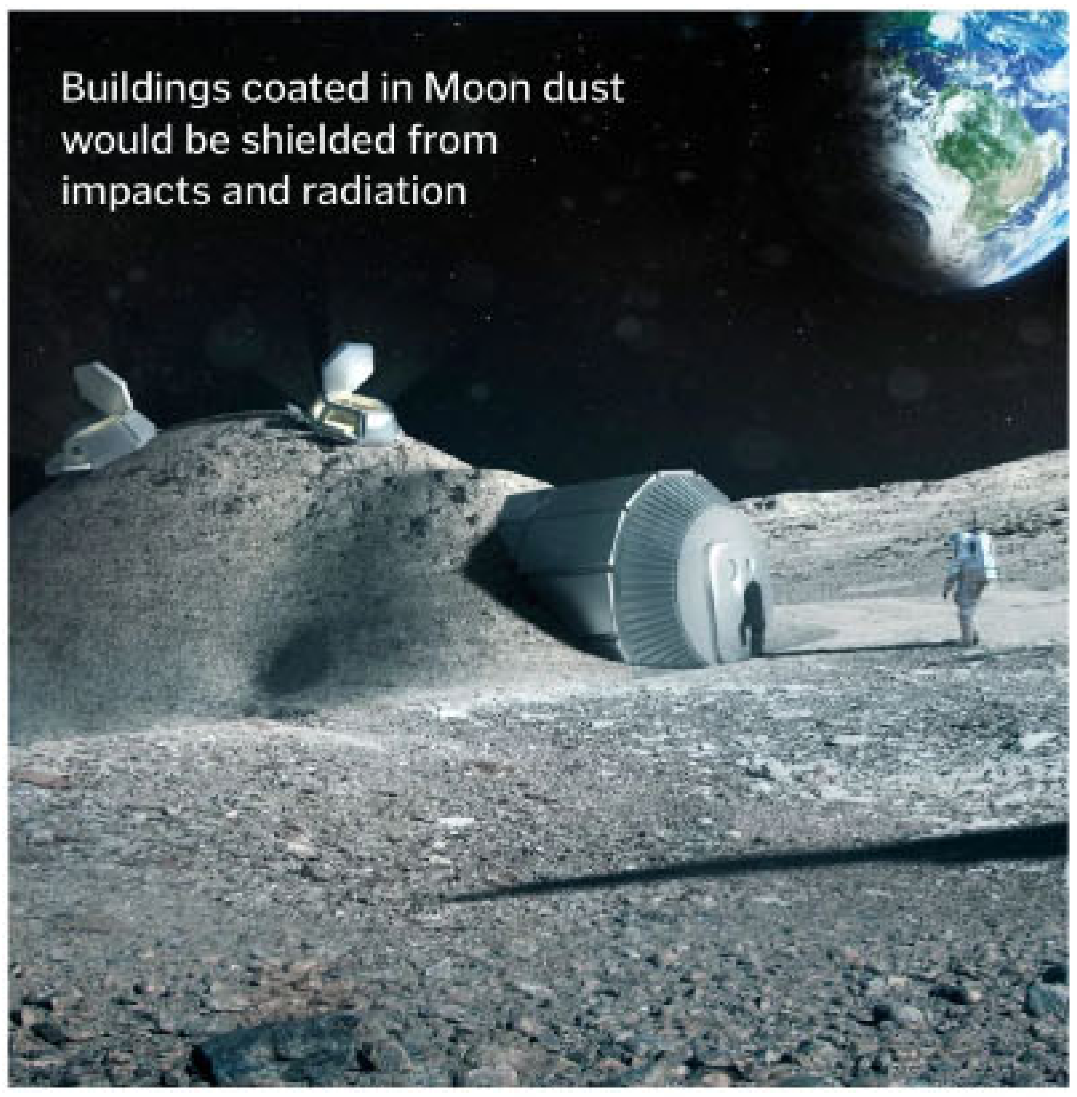
Flat-packed panels could also be shipped in from Earth to build sturdier dome or hangar structures, but it would be much more fuel-efficient to use building materials found on the surface of the Moon. When heated, lunar dust can be transformed into a tough solid that could be used to construct buildings and roads, and 3D printers could one day be used to make structures from the regolith.

In the right location, solar panels could provide renewable power for the base, and, if plants are able to grow on the Moon, it could one day be possible to set up a semi-sustainable farming and composting system. Then, if water, oxygen and hydrogen (rocket fuel) could be extracted from lunar dust, a base might even be able to become self-sufficient.

Unfortunately, there are still major challenges to be overcome before we reach this stage, not least the devastating effects of lunar dust. The dust seems to find its way inside even tightly sealed spaces, causing rapid damage to equipment. There are some ideas to get around this, including cable cars or covered transport tubes to minimise the disturbance on the surface, and clean rooms and air locks to keep inside spaces dust-free.

> "Solar panels could provide renewable power for the base"


Inflatable habitats are light, but vulnerable to asteroid impacts


Buildings coated in Moon dust would be shielded from impacts and radiation

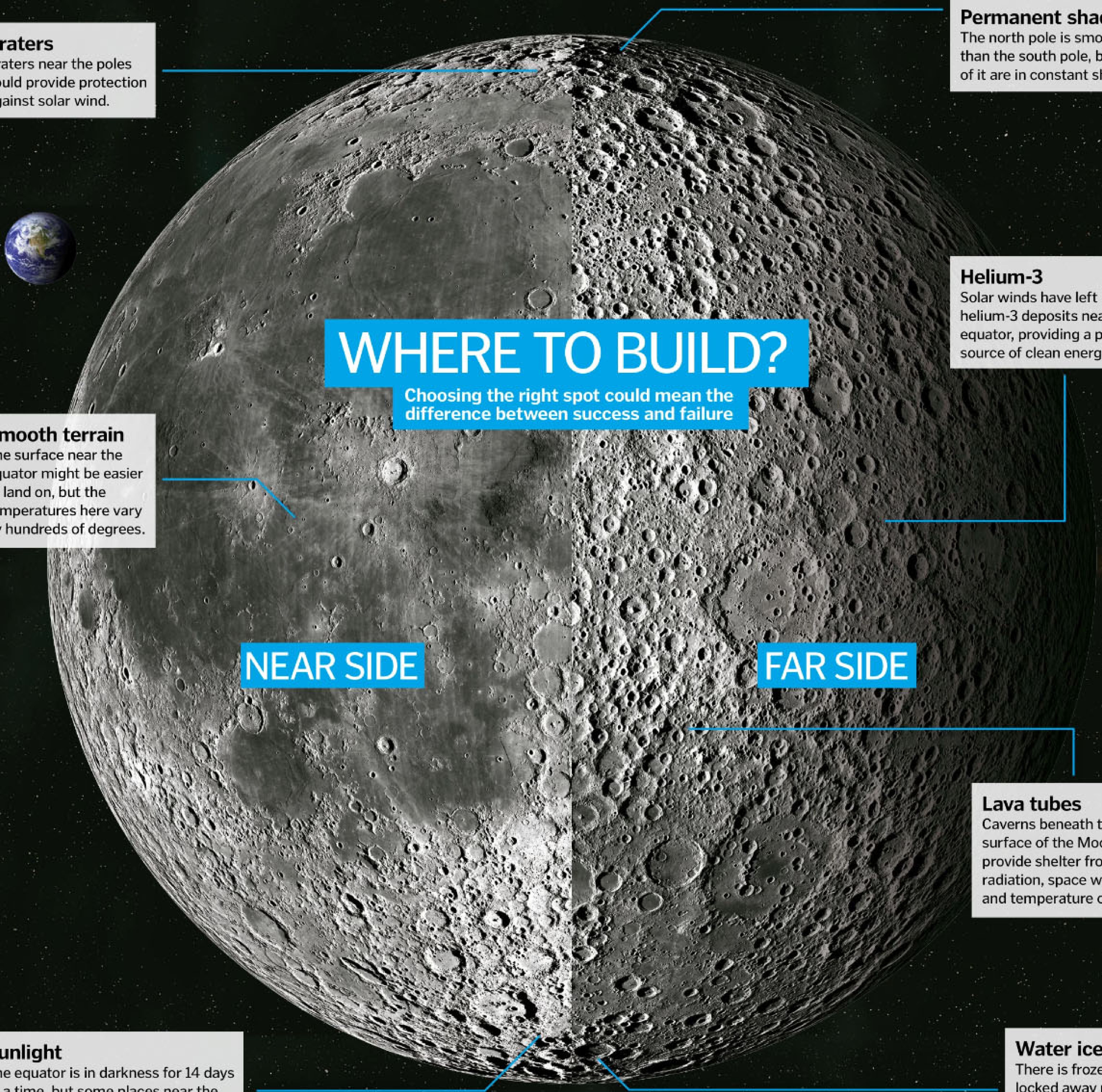
Dust from the Moon could be used as a material for 3D printing

Excavation equipment would need to resist the damaging effects of fine dust particles

DID YOU KNOW? *NASA held a Regolith Excavation Challenge to encourage engineers to built robots that can dig up lunar soil*

WHERE TO BUILD?

Choosing the right spot could mean the difference between success and failure



Craters
Craters near the poles could provide protection against solar wind.

Permanent shade
The north pole is smoother than the south pole, but parts of it are in constant shadow.

Helium-3
Solar winds have left rich helium-3 deposits near the equator, providing a potential source of clean energy.

Smooth terrain
The surface near the equator might be easier to land on, but the temperatures here vary by hundreds of degrees.

Lava tubes
Caverns beneath the surface of the Moon could provide shelter from radiation, space weather and temperature changes.

Sunlight
The equator is in darkness for 14 days at a time, but some places near the poles are in near constant sunlight.

Water ice
There is frozen water locked away near to the Moon's north and south poles.

Location, location, location

The Apollo missions landed close to the Moon's equator, where the surface is smooth and entering orbit is easy, but these regions have serious problems with temperature control. The Moon turns on its axis once every 28 Earth days, so daytime at the equator lasts for two weeks, and temperatures climb to more than 100 degrees Celsius. For the other two weeks, the same spot is plunged into total darkness and the surface cools to 150 degrees below freezing.

These wide fluctuations could pose real problems for buildings and equipment, and with sunlight absent for days at a time, solar power would be intermittent. Facing head on to the Sun and with little in the way of atmosphere, the equator is also blasted by radiation and solar winds.

At the poles, night and day are less dramatic. The surface is rougher, but certain areas receive sunlight for most of the year, and the temperature remains more stable at around zero degrees Celsius. There is also water ice trapped at the poles, which could provide gases, fluids and even rocket fuel.

One promising location is Shackleton Crater, which is found at the Moon's southern pole. It receives sunlight for around 80 per cent of the year, which could provide a near constant source of electricity from solar panels. Building a base near the equator would be more challenging, but underground habitats could provide enough protection in more exposed locations. Lava tubes like the Marius Hills pit could offer ready-made shelter from temperature fluctuations, solar wind, radiation and surface dust.

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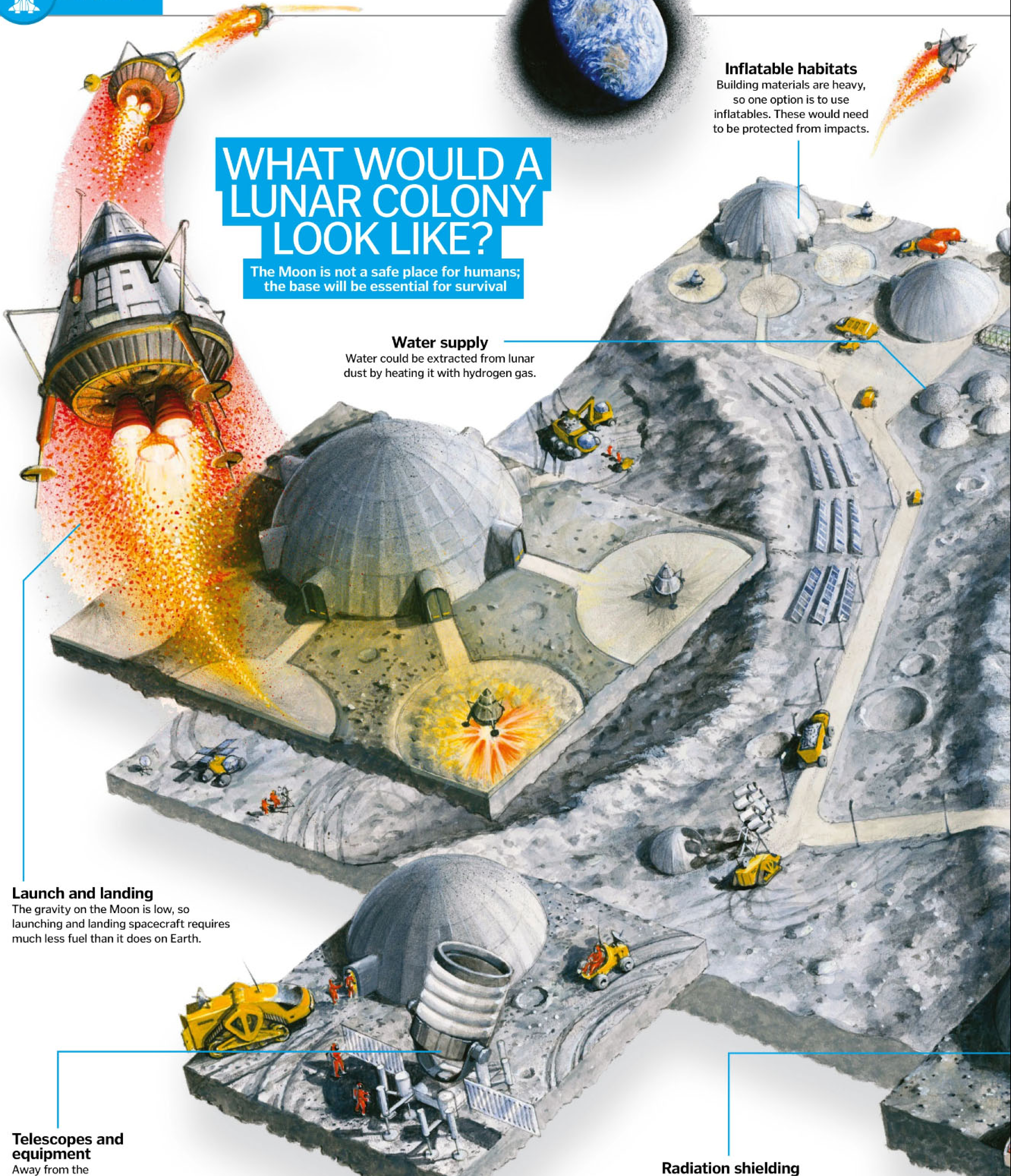
WHAT WOULD A LUNAR COLONY LOOK LIKE?

The Moon is not a safe place for humans; the base will be essential for survival



Inflatable habitats
Building materials are heavy, so one option is to use inflatables. These would need to be protected from impacts.

Water supply
Water could be extracted from lunar dust by heating it with hydrogen gas.

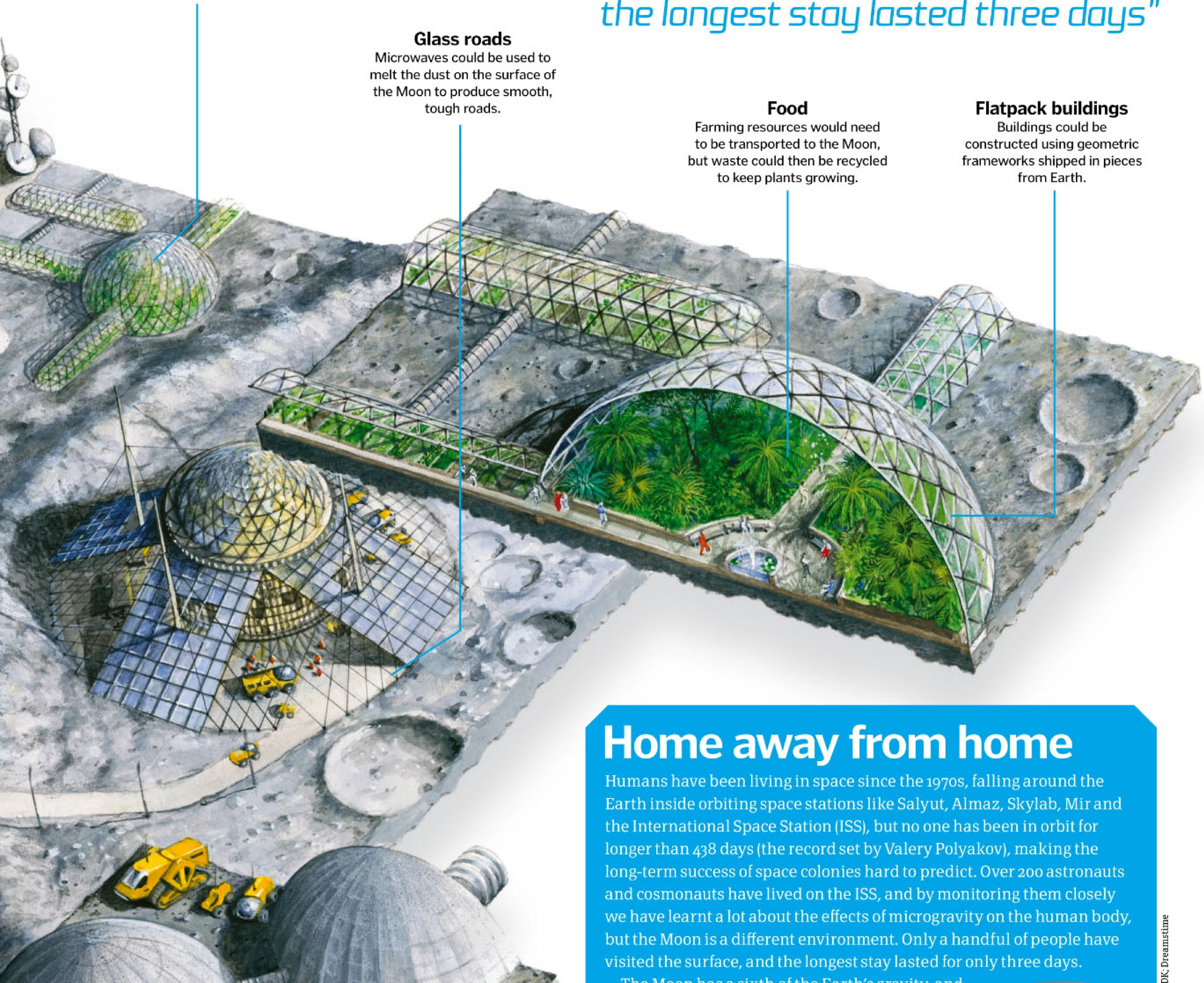
Launch and landing
The gravity on the Moon is low, so launching and landing spacecraft requires much less fuel than it does on Earth.

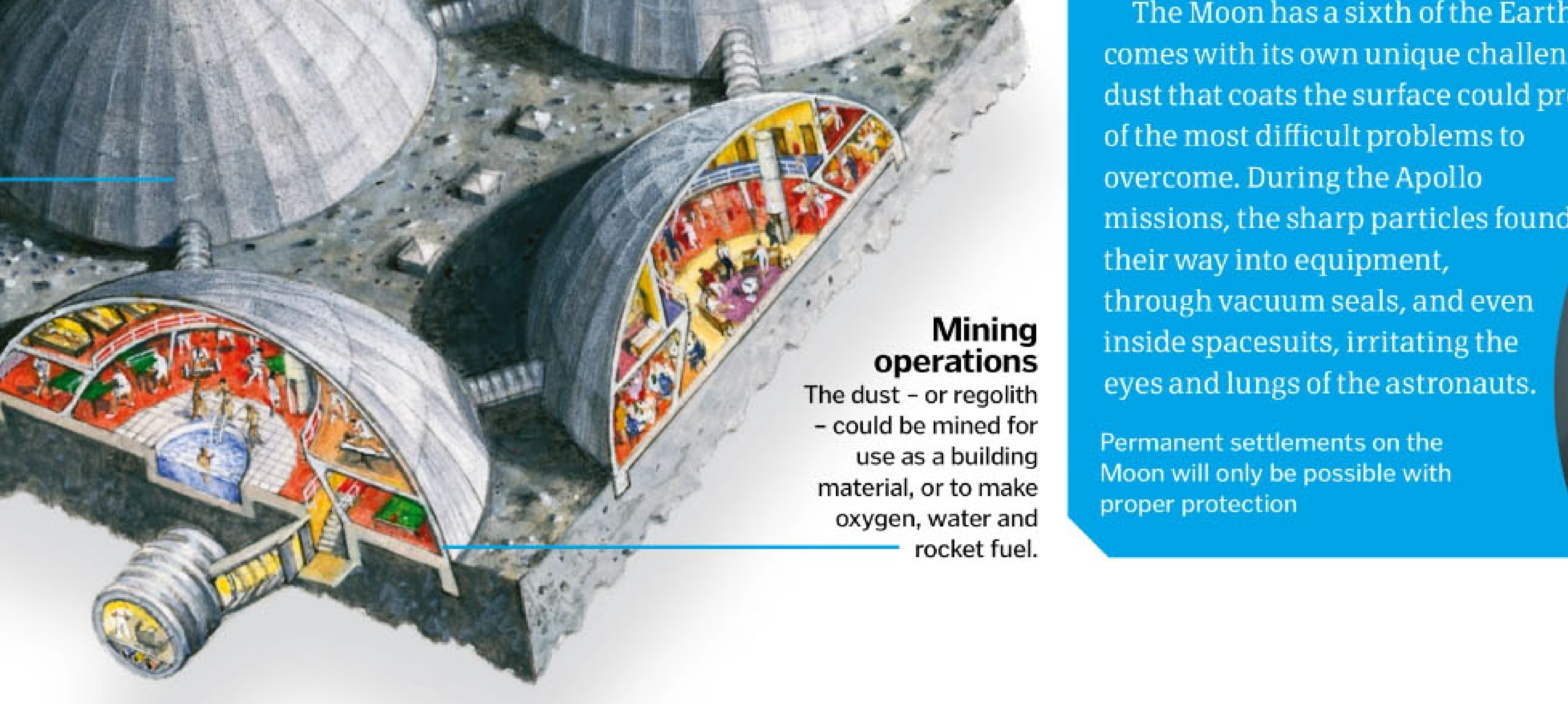
Telescopes and equipment
Away from the interference of Earth's atmosphere, a lunar base could house powerful telescopes.

Radiation shielding
Buildings would need to be protected from radiation. A popular idea is to bury them under layers of moon dust.

DID YOU KNOW? *The Moon is an average distance of 384,400km away, equal to about 30 Earths lined up side by side*

> *"Only a handful of people have visited the Moon's surface, and the longest stay lasted three days"*





Oxygen
Water extracted from the lunar surface could be split into hydrogen and oxygen using a technique called electrolysis.

Glass roads
Microwaves could be used to melt the dust on the surface of the Moon to produce smooth, tough roads.

Food
Farming resources would need to be transported to the Moon, but waste could then be recycled to keep plants growing.

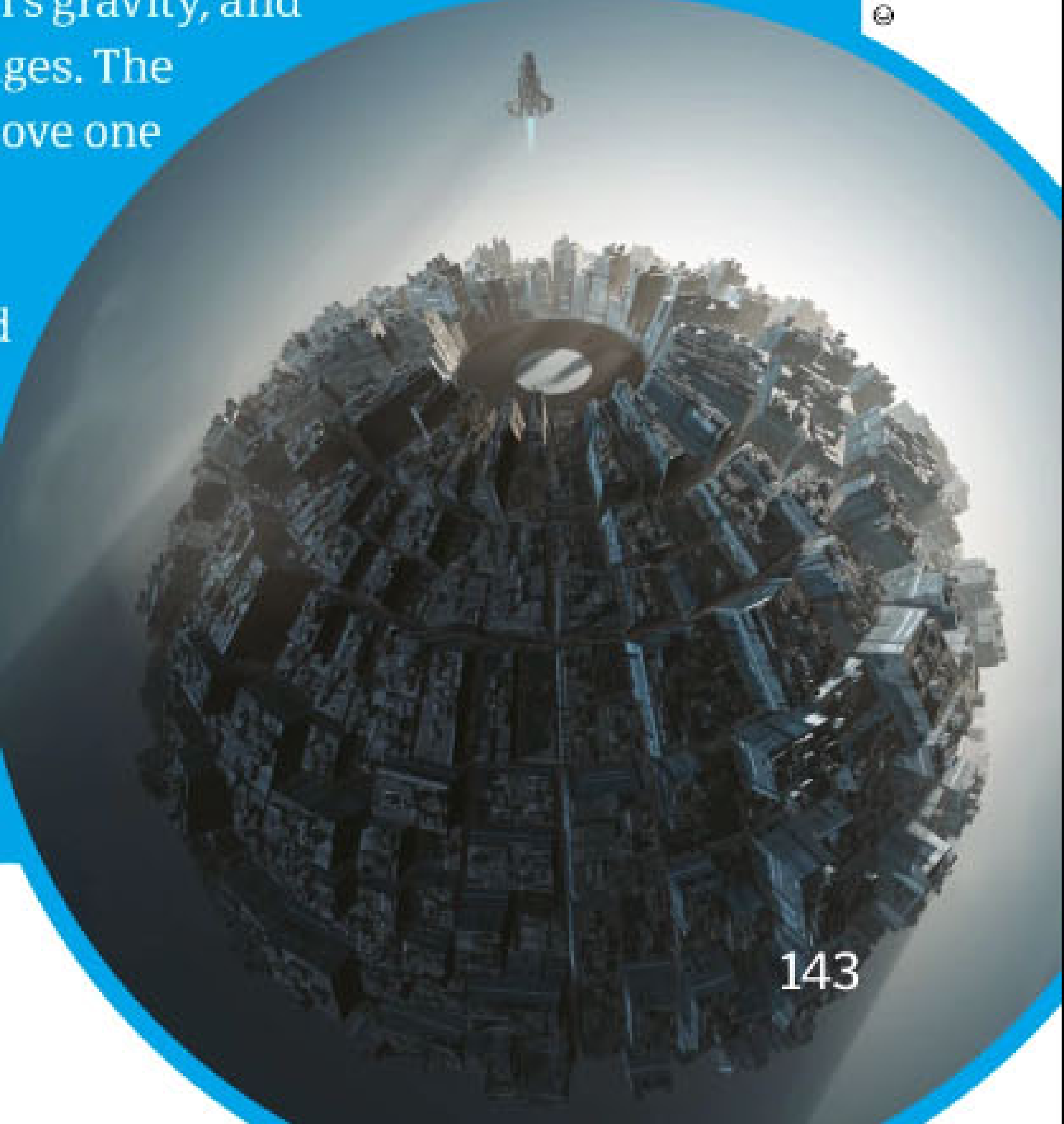
Flatpack buildings
Buildings could be constructed using geometric frameworks shipped in pieces from Earth.

Mining operations
The dust – or regolith – could be mined for use as a building material, or to make oxygen, water and rocket fuel.

Home away from home

Humans have been living in space since the 1970s, falling around the Earth inside orbiting space stations like Salyut, Almaz, Skylab, Mir and the International Space Station (ISS), but no one has been in orbit for longer than 438 days (the record set by Valery Polyakov), making the long-term success of space colonies hard to predict. Over 200 astronauts and cosmonauts have lived on the ISS, and by monitoring them closely we have learnt a lot about the effects of microgravity on the human body, but the Moon is a different environment. Only a handful of people have visited the surface, and the longest stay lasted for only three days.

The Moon has a sixth of the Earth's gravity, and comes with its own unique challenges. The dust that coats the surface could prove one of the most difficult problems to overcome. During the Apollo missions, the sharp particles found their way into equipment, through vacuum seals, and even inside spacesuits, irritating the eyes and lungs of the astronauts.



Permanent settlements on the Moon will only be possible with proper protection

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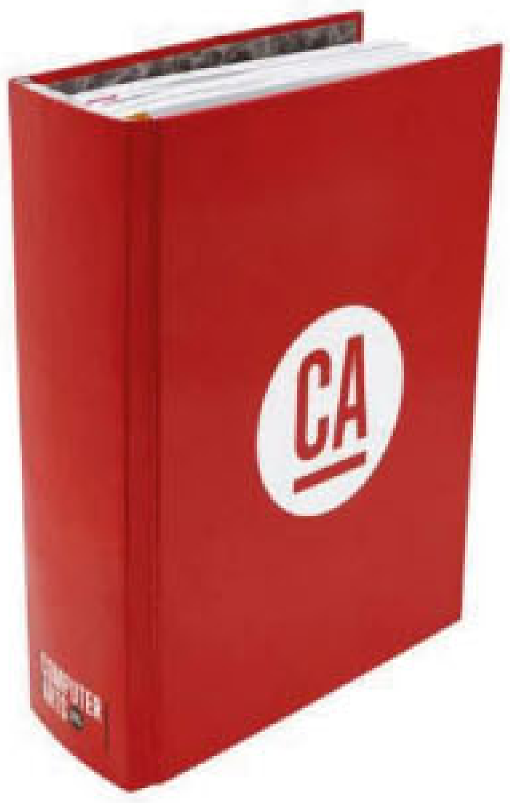

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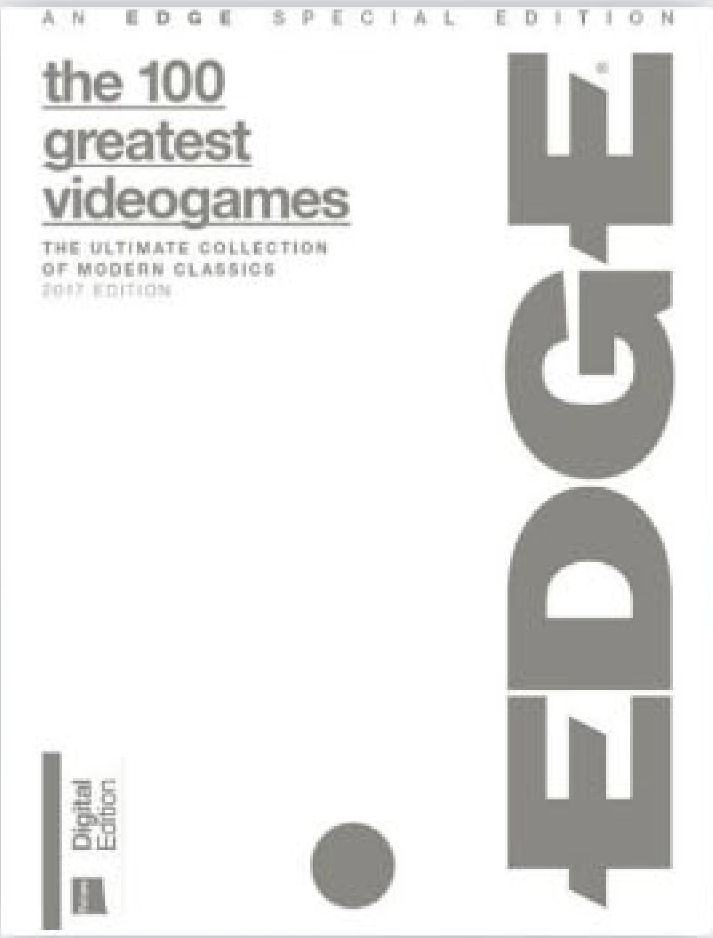

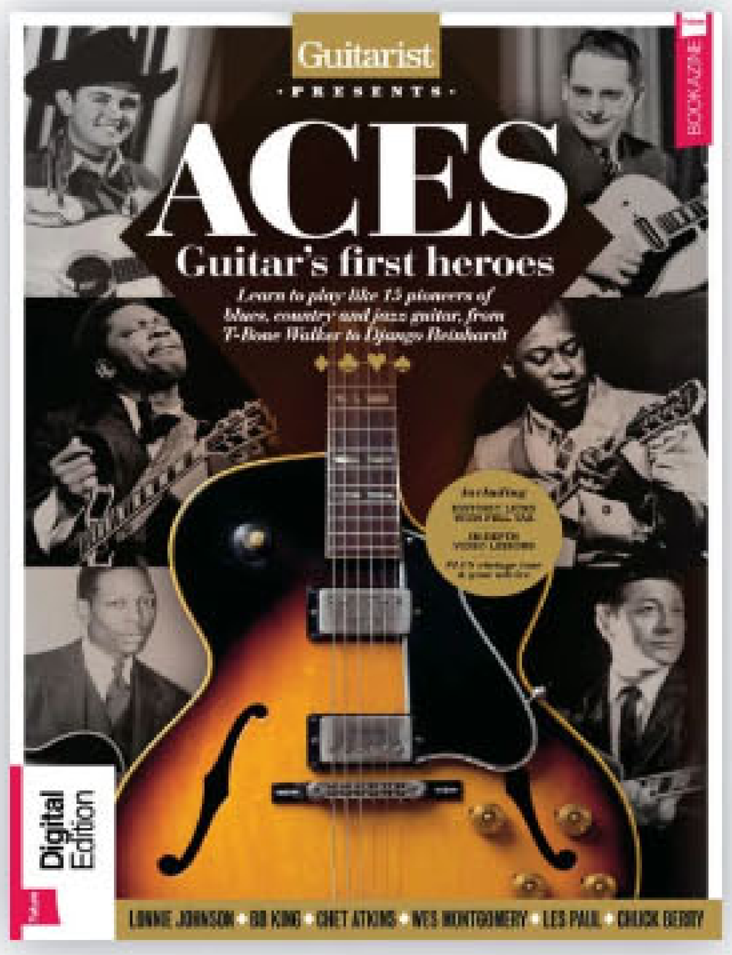

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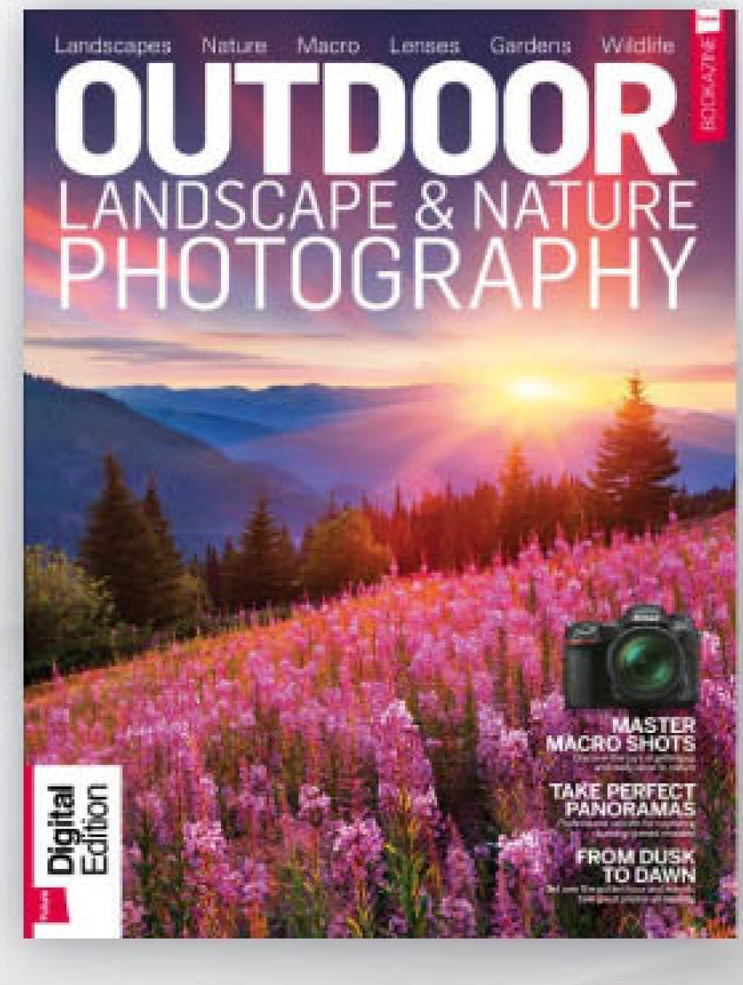

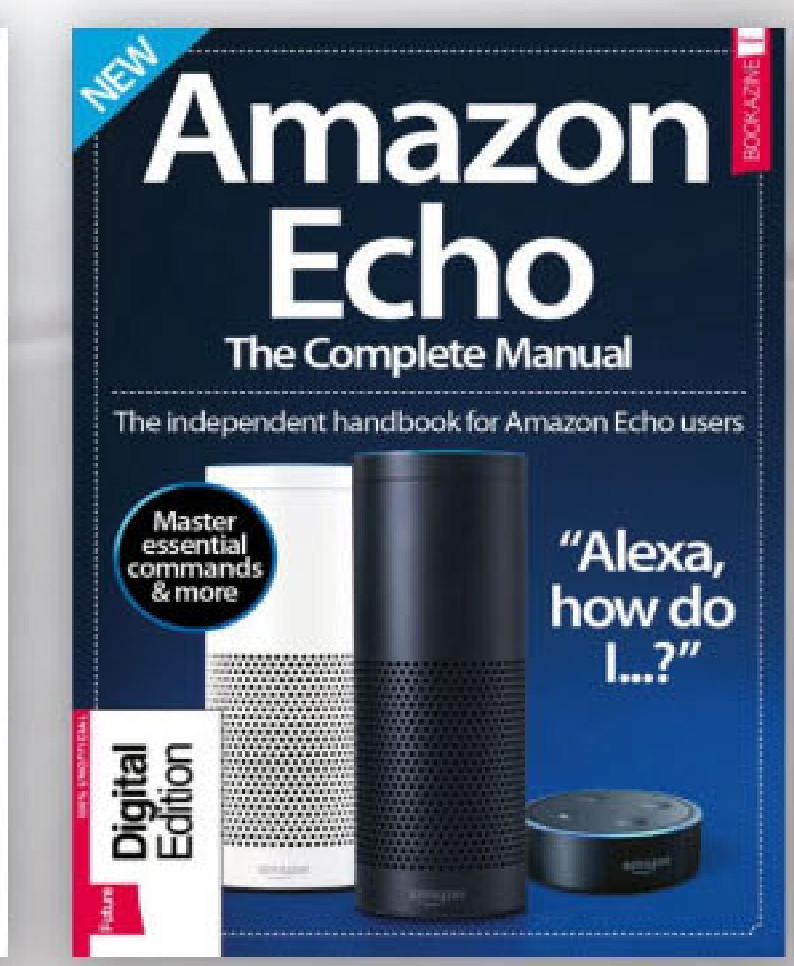

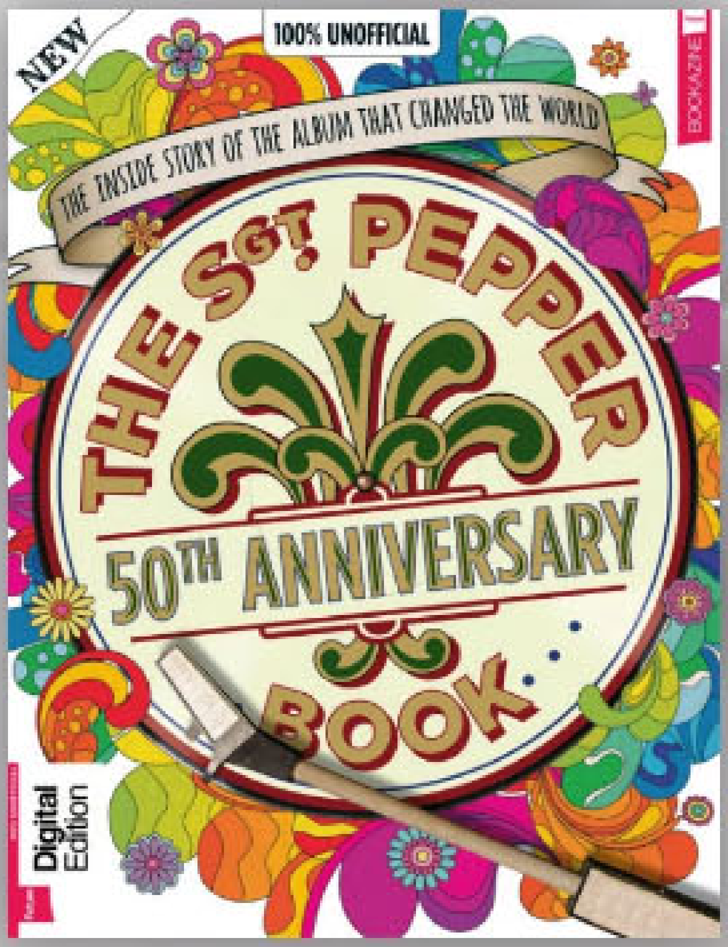

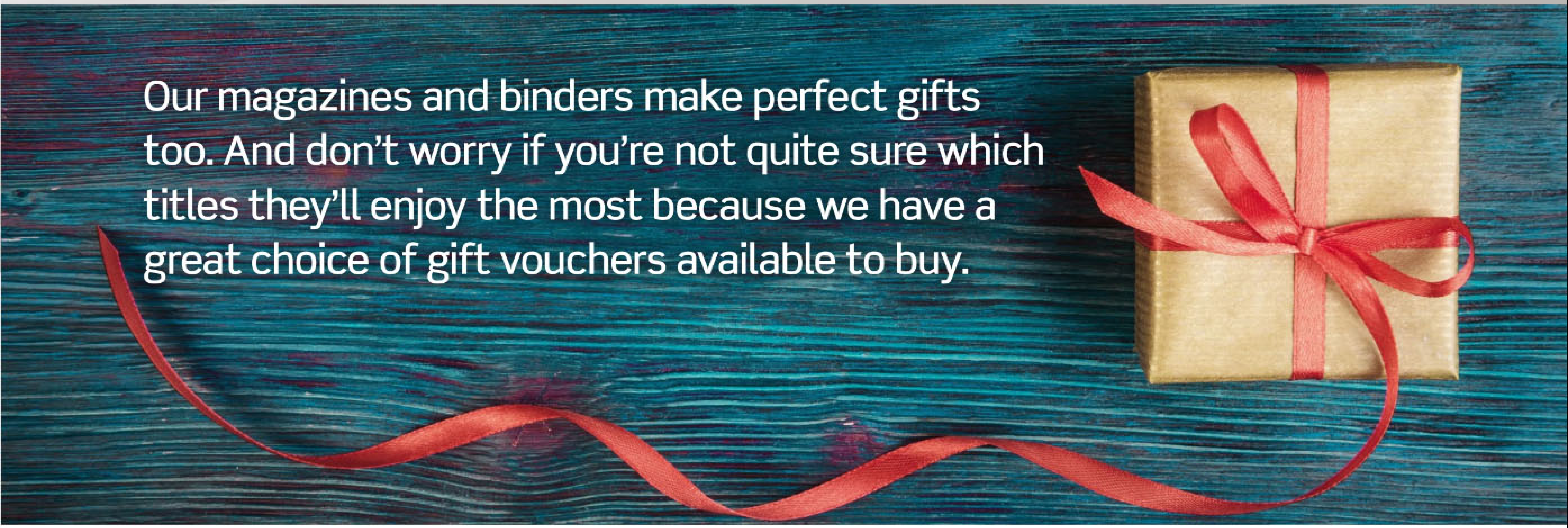

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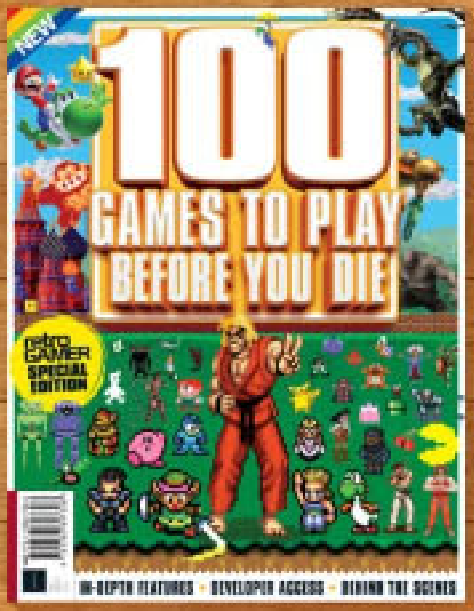

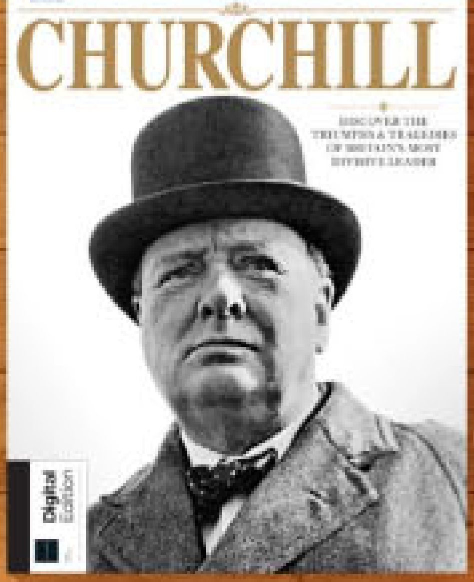

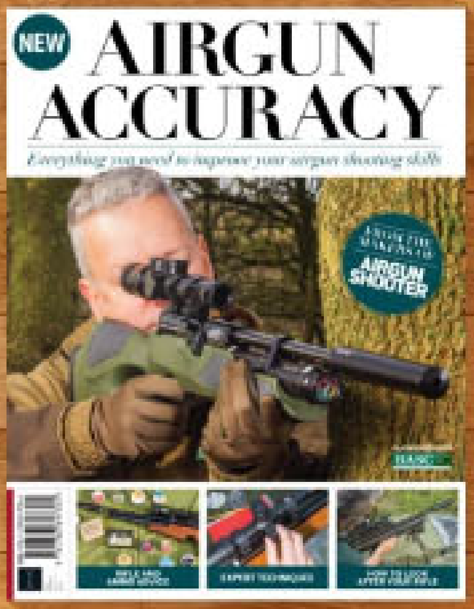

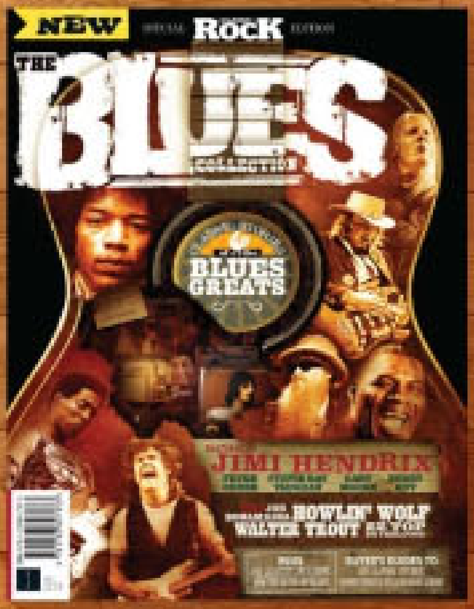

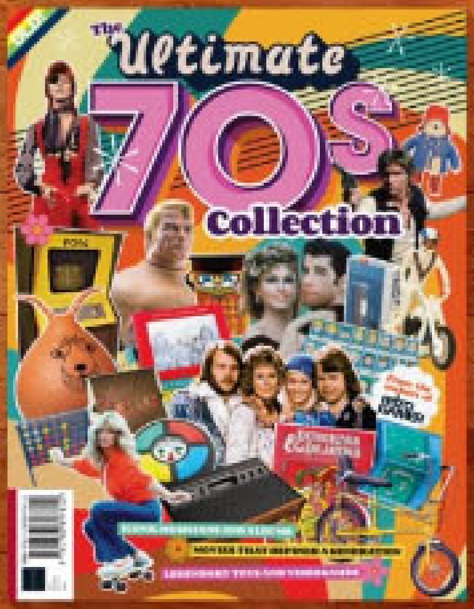

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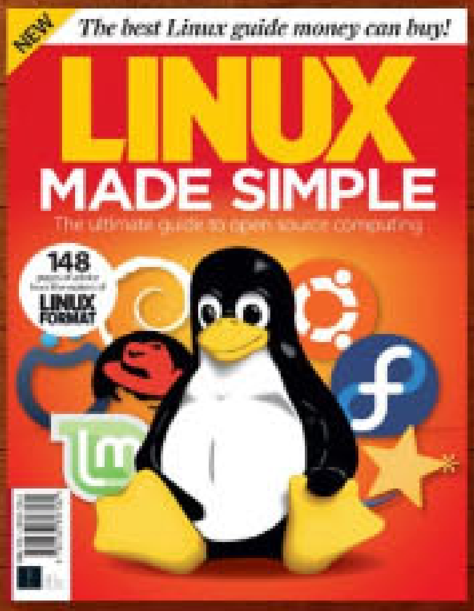

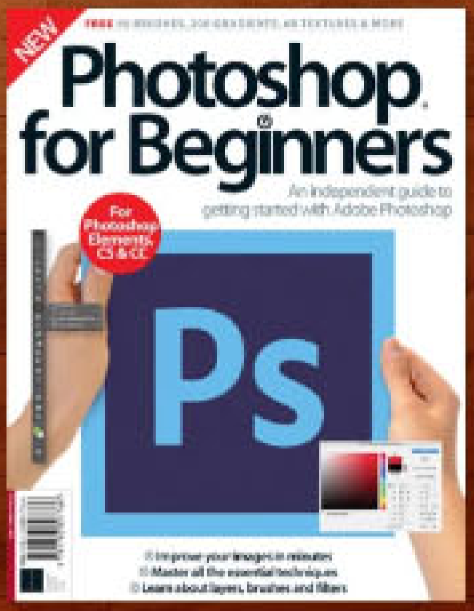

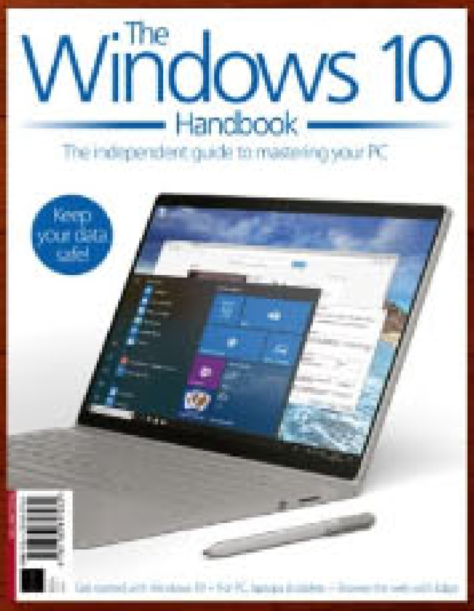

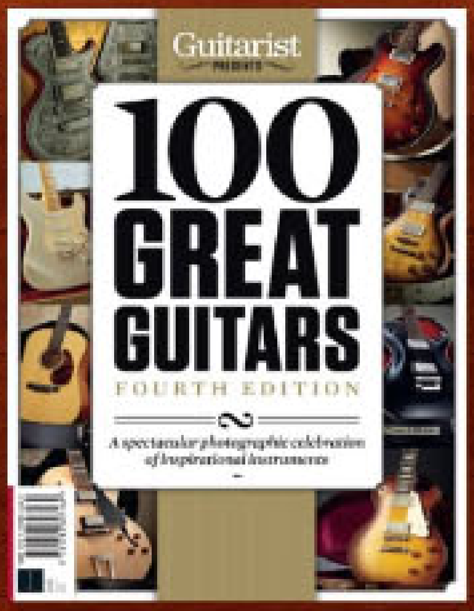

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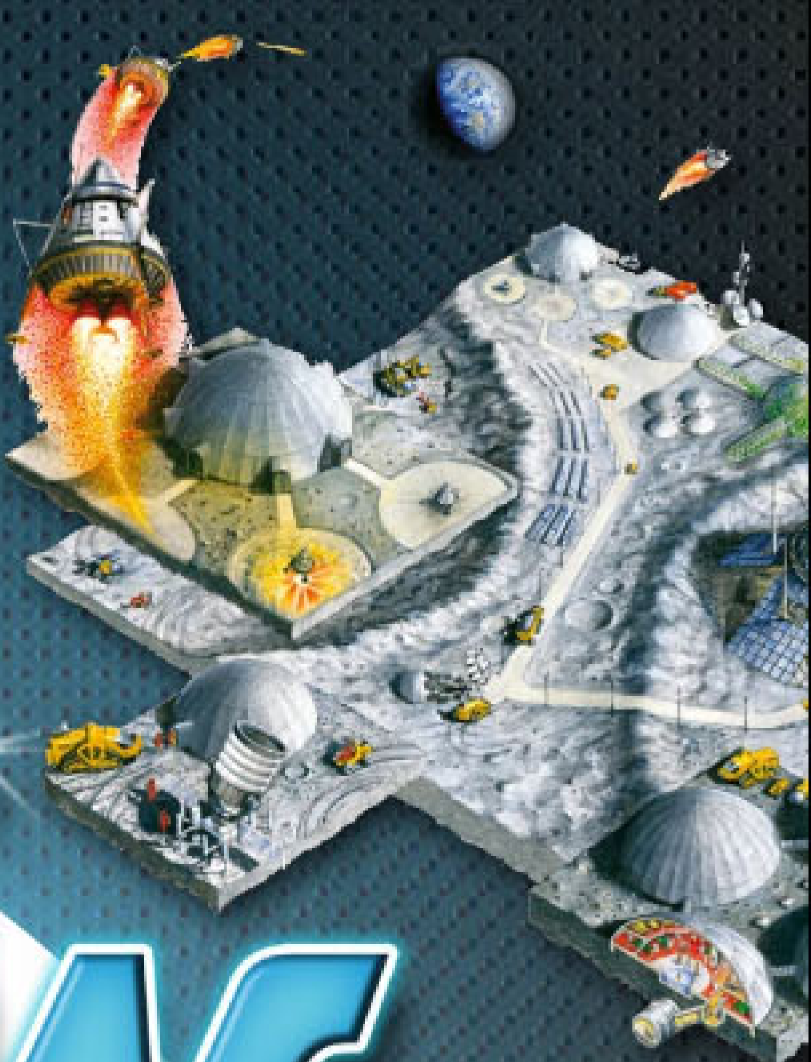

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